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HIGH-RATE AND DUAL-MEDIA FILTRATION STUDY, EASLEY, SOUTH CAROLINA, WATER PLANT

James F. Kriessl, et al

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

August 1965

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PROJECT REPORT

HIGH-RATE AND DUAL-MEDIA FILTRATION STUDY

EASLEY, SOUTH CAROLINA, WATER PLANT

by

James F. Kreissl, Kenneth A. Dostal, and Gordon G. Robeck

Engineering Section
Basic and Applied Sciences Branch
Division of Water Supply and Pollution Control

August 1965

U. S. Department of Health, Education, and Welfare
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Robert A. Taft Sanitary Engineering Center
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HIGH-RATE AND DUAL-MEDIA FILTRATION STUDY - EASLEY, SOUTH CAROLINA, WATER PLANT

by

James F. Kreissl, Kenneth A. Dostal, and Gordon G. Robeck

Prefilter and chlorination improvements and continuing high construction costs of filter installations have created a need for a review of the role that filtration plays in the purification of our surface water supplies. In accordance with this need the Sanitary Engineering Center, in cooperation with State Health Departments and water plants, is continuing the collection of data on the influence of high-rate and dual-media filtration and of modifications in prefiltration treatment on finished water quality. This report includes the results from a study encompassing both high-rate and dual-media filtration conducted at a 4-mgd water treatment plant located in Easley, South Carolina, during the latter half of 1963 and the first half of 1964.

The results of this study corroborate previous work:[1,2] when adequate prefiltration treatment is afforded, effluent of high quality, determined turbidimetrically and bacteriologically, can be obtained with filtration rates between 2 and 6 gpm per square foot. The results also indicate that longer filter runs with the use of dual-media filters result in effluent quality equal to that of sand filters.

OBJECTIVES

This study resulted from a desire expressed by the Easley Water and Light Department to treat more water with their present plant and a request from the South Carolina State Board of Health to collect data from a plant with sand filters operated at high flow rates. This effort was to supplement the Gaffney, South Carolina, study[1] of 1959 through 1961 since that plant treats

similar water, but employs anthracite filters.

To provide more information for small water plants contemplating high-rate filtration procedures, the Engineering Section, Basic and Applied Sciences Branch, Division of Water Supply and Pollution Control, at the Sanitary Engineering Center agreed to help investigate filter performance at various filtration rates in cooperation with the State of South Carolina and the City of Easley. This provided the opportunity to continue the work begun at Gaffney as well as to conduct small-scale pilot studies with a dual-media filter and the soft, Piedmont-area water.

The Easley project consisted mainly of operating a pair of full-scale sand filters at various filtration rates, monitoring the passage of turbidity and coliforms, and measuring the development of headloss throughout each test run. The runs were repeated several times during each season.

RAW WATER SOURCES AND QUALITY

During the winter months the normal daily demand on the Easley water treatment plant is supplied by the Burdine Creek supply by means of two pumps with a combined capacity of 3,200 gpm. A small dam provides sufficient water depth for the intake, but does not provide appreciable storage. When the peak demands of the warmer months occur, additional raw water is obtained from the Saluda River, where two more pumps of a combined 2,150-gpm rate are located. These two pumps and one of the Burdine pumps are normally used during these periods. If peak demands exceed this combined flow, an additional 350-gpm pump located at Mad Dog Creek is employed.

The Saluda River water is pumped approximately 5 miles in a 16-inch cast-iron pipe to the Burdine Creek pumping station. At this point the flows

can be mixed or kept separate in the 16-inch and two 10-inch pipes. The water is pumped another mile to Mad Dog Creek, where that inflow in brought into one of the 10-inch lines. The three lines are joined immediately before the water enters the treatment plant, which is about another mile beyond the point where the Mad Dog Creek supply adjoins. The location of these facilities are shown in Figure 1.

During the year of the field study, the influent to the water plant had the following range in characteristics: pH, 6.0 to 7.0; temperature, 3° to 23°C; turbidity, < 25 to 1000 J.u.; alkalinity, 10 to 24 mg/liter as $CaCO_3$; CO_2, 2 to 10 mg/liter as CO_2.

DESCRIPTION AND OPERATION OF WATER PLANT

The 1949 addition to the Easley water plant increased its capacity to approximately 4 mgd. Alum and lime are added just before the raw water enters a chemical-mixing chamber, which is 70 feet long, 32 inches wide, and 10 feet deep. The chamber has over-and-under baffles spaced from 31 inches apart at the influent end to 55 inches at the effluent end. The alum added coagulates the water and the lime insures sufficient alkalinity to react with the alum and to adjust the pH.

From the chemical-mixing chamber, the water flows to the flocculation chamber, which consists of three channels, each 40 feet long, 6 feet wide, and 10 feet deep. Over-and-under baffles are spaced from 2-1/2 to 7 feet apart from inlet to outlet. From the flocculation chamber, the water flows through a flume and stilling walls into six settling basins.

The first two basins are 60 feet long, 20 feet wide, and 10 feet deep, and hold approximately 90,000 gallons each. The middle two basins are 73 feet

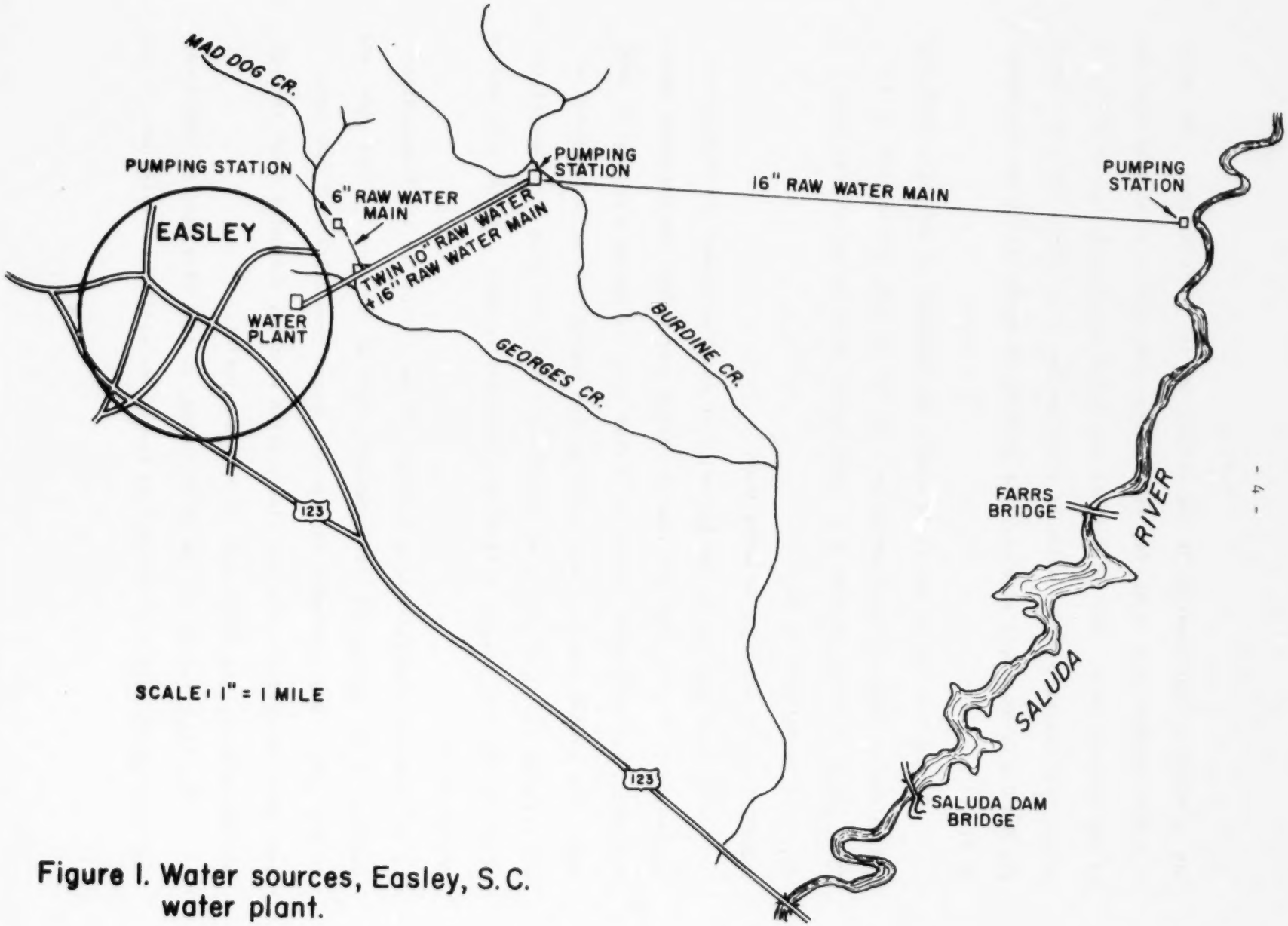

Figure 1. Water sources, Easley, S.C. water plant.

long, 30 feet wide, and 10 feet deep, and hold about 160,000 gallons each. The two newest basins are 86 feet long, 32 feet wide, and 12 feet deep, and hold 250,000 gallons each. Thus, the overflow rate at design capacity for all basins is 325 gpd per square foot, and the theoretical detention times is 6 hours. Outlets from the sedimentation basins consist of a series of 2-inch pipes imbedded in the concrete wall. The settled water flows through these pipes into a trough. From this trough, the water is delivered to the four pairs of filters by a manifold system so that water from any settling basin may be delivered to any filter.

The filtration is accomplished by eight filters, each rated at 0.5 mgd (2 gpm per square foot). The filter media consists of 27 inches of sand supported by 12 inches of gravel. Two of the filters have perforated pipe underdrains, and the other six have Wheeler Bottoms. The method proposed by Baylis[3] to determine the effective size of filter sand gave an effective size of 0.41 millimeters for the filters employed in this study. During the testing period there was no provision for surface wash of the filters although remedial measures are now being taken to eliminate possible mudball formation. Backwashing of the filters is accomplished in pairs with a flow of 7.8 gpm per square foot (12.5 in/min) for 10 to 12 minutes, after a headloss value of 6 feet has been attained with a filtration rate of 2 gpm per square foot.

Rate of flow control for the individual filters is provided by hydraulic butterfly valves. These valves can be set to permit a wide range of filtration rates, which are measured by Venturi meters in the filter effluent piping.

Chlorination before and after the coagulation-filtration process disinfects the Easley water. After filtration the water is treated with soda

ash to adjust the pH to 8.0 to 8.2 to minimize possible corrosion in the distribution system.

Test Equipment

The turbidity of the influent to and effluents from the sand filters was measured by a single Hach turbidimeter and recorder that use solenoid valves and an automatic recycling timer. Another Hach instrument was used to measure and record the effluent turbidity from the small dual-media test filter. Raw water turbidity was measured periodically with a Jackson candle turbidimeter.

The plant layout in Figure 2 indicates the locations of the turbidity and coliform samples. Membrane filter techniques[4] were used to count coliforms.

Figure 3 shows the construction details of the dual-media test filter made of plexiglass. Head loss development at the various depths was recorded throughout each run by a system of timer-controlled solenoid valves applying differential pressures to a sensing unit attached to a recorder. The rate of flow control for the dual-media filter was accomplished with a metering unit consisting of gear pumps, hydraulic transmission, and an electric motor.

Test Procedures

Prechlorination was discontinued the day before the start of a test run and was not restarted until the run was completed. Both the full-scale filters and the small dual-media filters were backwashed just before the run began. The large-filter runs were not of a continuous nature; they were stopped when the water plant was shut down in the evening and restarted with the rest of the plant the following morning. Corresponding runs with the dual-media filter were continuous until a 6-foot head loss was attained.

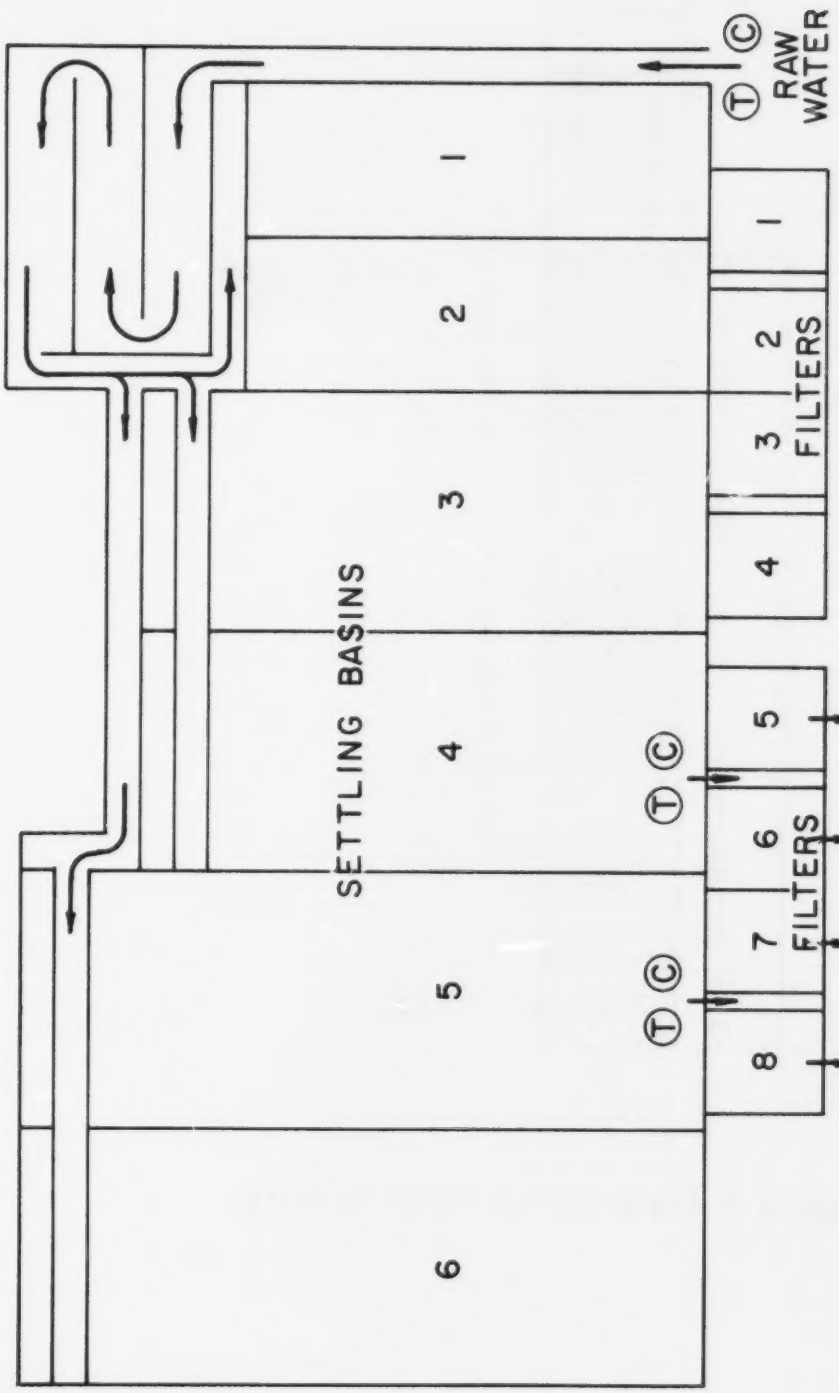

Figure 2. Sampling locations, Easley, S. C., water plant.

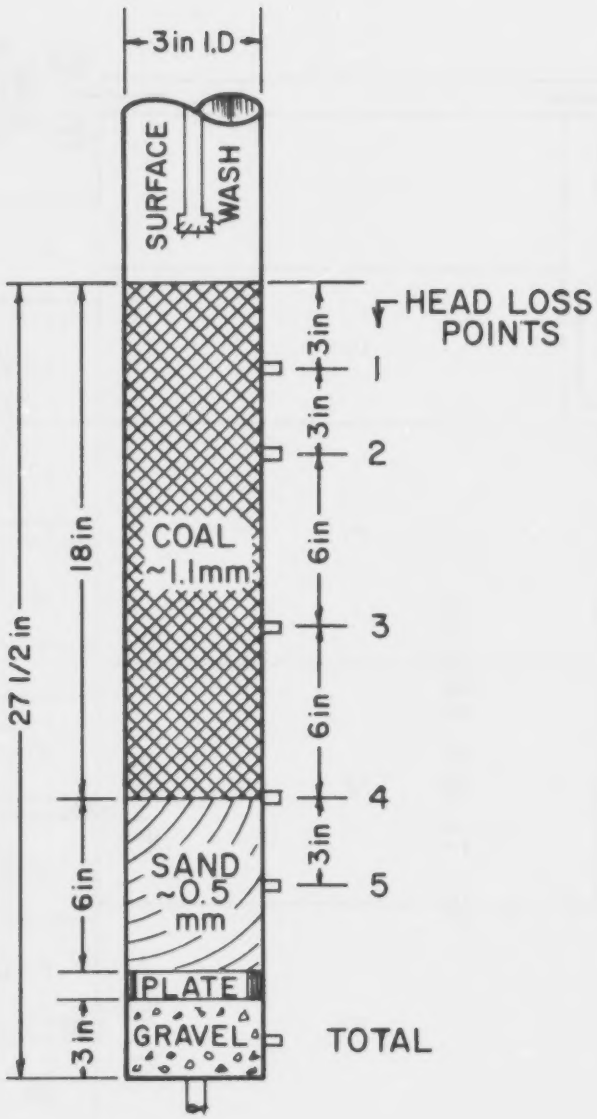

Figure 3. Dual-media filter details.

For each run, the two full-scale sand test filters had an average output of 4 gpm per square foot. The combinations used were 6 and 2, 5 and 3, and 4 and 4 gpm per square foot. The dual-media filter was operated at a filtration rate corresponding to that of one of the large test filters.

To test the possibility of increasing the capacity of the existing plant, the sedimentation tanks were also overloaded during the test periods (Table I); only three or four of the six available sedimentation basins were used.

Plant personnel made coliform determinations on periodic grab samples of the raw water, influent to the filters, and effluents from the dual-media and the two large filters.

RESULTS:

Turbidity

The turbidity results of all the test runs are presented graphically in Figures 4 through 31, and the runs are summarized in Table II.

The nine runs completed during the summer series that utilized only the full-scale sand filters are presented in Figures 4 through 8. Except for the initial portion of runs 1 and 2, the results of these runs show no significant degradation in effluent quality due to filtration rates greater than 2 gpm per square foot. In the first two runs, the filter effluent turbidity was highly dependent on the turbidity of the settling basin effluent. Inadequate coagulation, brought on by rapidly changing raw-water turbidity, seemed to be responsible for this troublesome period.

TABLE I

HYDRAULIC LOADING OF SETTLING BASINS DURING TEST RUNS

Run no.	Starting Date	Basins used		Production mgd	Overflow rate gpd/ft^2	Percentage of underload, (-) or overload (+)
		No.	Area, ft^2			
			Summer series			
1	6/17/63	-	-	-	-	-
2	6/19/63	-	-	-	-	-
3	6/25/63	-	-	-	-	-
4	6/26/63	-	-	-	-	-
5	7/1/63	-	-	-	-	-
6	7/8/63	4,5,6	7,680	3.21	418	+29
7	7/15/63	4,5,6	7,680	3.24	422	+30
8	7/22/63	4,5,6	7,680	3.43	447	+38
9	7/28/63	-	-	-	-	-
			Fall series			
1	9/24/63	4,5,6	7,680	3.36	437	+34
2	9/25/63	4,5,6	7,680	3.36	437	+34
3	10/2/63	4,5,6	7,680	3.48	453	+39
4	10/8/63	4,5,6	7,680	3.82	498	+53
5	10/9/63	4,5,6	7,680	3.88	505	+55
6	10/14/63	4,5,6	7,680	3.80	495	+52
7	10/16/63	4,5,6	7,680	3.68	479	+47
8	10/22/63	4,5,6	7,680	-	-	-
9	10/23/63	4,5,6	7,680	-	-	-

TABLE I (Contd.)

Run no.	Starting Date	Basins used		Production mgd	Overflow rate, gpd/ft^2	Percentage of underload, (-) or overload (+)
		No.	Area, ft^2			
			Winter series			
1	11/12/63	1-6	12,260	3.59	293	-9
2	11/19/63	1,4,5,6	8,880	3.63	409	+26
3	11/26/63	1,4,5,6	8,880	2.85	321	-1
4	12/3/63	4,5,6	7,680	3.54	461	+42
5	12/10/63	4,5,6	7,680	3.50	456	+40
6	12/17/63	1,4,5,6	8,880	3.70	417	+28
7	1/6/64	1,4,5,6	8,880	3.56	401	+23
8	1/14/64	2,4,5,6	8,880	3.20	360	+11
9	1/21/64	1,3,4,5	8,310	3.22	387	+19
10	2/11/64	-	-	-	-	-
			Spring series			
1	3/3/64	1,4,5,6	8,880	3.53[a]	398	+22
2	3/11/64	1,4,5,6	8,880	3.65[a]	411	+26
3	3/15/64	1,4,5,6	8,880	3.64[a]	410	+26
4	3/24/64	2,4,5,6	8,880	3.07[a]	346	+6
5	4/7/64	1-6	12,260	3.16[a]	258	-21
6	4/14/64	1,4,5,6	8,880	3.52[a]	397	+22
7	4/29/64	1,4,5,6	8,880	3.68[a]	415	+28
8	5/5/64	-	-	-	-	-

a - Based on a normal 16-hour operational period, no other information available.

TABLE II

SUMMARY OF TURBIDITY RESULTS OF TEST RUNS

Run no.	Starting date	Filter no.	Rate, gpm/ft^2	Length of run, hr.	Final head loss, ft	Turbidity, J.u.	
						Max.	Avg.
			Summer series				
1	6/17/63	5	6	31	8.0	5.1	1.5
		8	2	36	5.6	4.1	1.3
2	6/19/63	6	6	28	7.1	5.5	0.7
		7	2	34	3.7	3.8	0.6
3	6/25/63	5	5	28	7.1	0.2	0.2
		7	3	38	6.8	0.2	0.1
4	6/26/63	6	5	14	7.3	0.2	0.1
		8	3	5	1.3	0.1	0.1
5	7/1/63	5	4	45	6.2	0.4	0.2
		7	4	45	6.0	0.2	0.2
6	7/8/63	6	6	35	6.2	0.2	0.1
		8	2	35	4.5	0.1	0.1
7	7/15/63	5	5	28	6.0	0.6	0.2
		7	3	28	6.0	0.3	0.2
8	7/22/63	6	4	30	4.6	0.4	0.2
		8	4	30	6.0	0.2	0.1
9	7/28/63	5	2	18	2.0	0.7	0.2
		7	6	18	7.0	0.3	0.2
			Fall series				
1	9/24/63	5	6	22	6.4	-	-
		7	2	22	3.9	-	-
2	9/25/63	6	5	21	6.0	0.2	0.1
		8	3	21	4.9	0.1	0.1
3	10/2/63	5	4	30	6.0	0.6	0.2
		7	4	30	5.9	0.2	0.2
4	10/8/63	6	6	16	6.2	0.7	0.3
		8	2	16	2.0	0.6	0.2
5	10/9/63	5	5	22	6.2	0.2	0.1
		7	3	22	3.4	0.2	0.1

TABLE II (Contd.)

Run no.	Starting date	Filter no.	Rate, gpm/ft^2	Length run, hr.	Final head loss, ft	Turbidity, J.u.	
						Max.	Avg.
6	10/14/63	6	4	26	6.8	0.2	0.1
		8	4	26	6.3	0.1	0.1
7	10/16/63	5	2	16	2.8	0.2	0.1
		7	6	16	5.6	0.2	0.1
8	10/22/63	6	3	16	4.4	4.6	1.0
		8	5	16	6.0	3.0	0.6
9	10/23/63	5	4	16	6.3	> 6	3
		7	4	16	6.0	> 6	3.5
			Winter series				
1	11/12/63	5	6	9.5	5.9	0.1	0.1
		7	2	9.5	4.5	0.1	0.1
		DM[a]	6	30	6.2	0.8	0.5
2	11/19/63	6	5	17	5.5	0.1	0.1
		8	3	17	2.8	0.1	0.1
		DM	5	84	6.1	0.1	0.1
3	11/26/63	5	4	30	5.8	0.1	0.1
		7	4	30	6.0	0.1	0.1
		DM	4	83	6.0	1.1	0.2
4	12/3/63	6	6	8.5	6.1	3	1
		8	2	8.5	1.4	2	0.8
		DM	6	44	6.0	5	1
5	12/10/63	5	5	16	5.8	-	-
		7	3	16	3.7	-	-
		DM	5	55	6.0	3	0.5
6	12/17/63	6	4	17	5.9	4	1.5
		8	4	17	6.0	4	1.5
		DM	4	47	6.2	7	1.5
7	1/6/64	5	2	14	3.5	2.5	0.8
		7	6	14	5.8	2	0.7
		DM	6	30	5.9	6.5	3

a - Small dual-media filter

TABLE II (Contd.)

Run no.	Starting date	Filter no.	Rate gpm/ft^2	Length run, hr.	Final head loss, ft.	Turbidity, J.u.	
						Max.	Avg.
8	1/14/64	6	3	20	4.6	1.2	0.5
		8	5	20	6.4	1.0	0.5
		DM	5	48	6.0	5	1
9	1/21/64	5	4	18	5.6	3	0.5
		7	4	18	6.0	3	0.4
		DM	4	49	6.2	> 6	1.5
10	2/11/64	5	3	36	6.4	0.1	0.1
		7	3	36	5.4	0.1	0.1
		DM	3	111	6.3	0.3	0.1
			Spring series				
1	3/3/64	5	6	14	5.8	6	2.5
		7	2	14	1.6	5	2
		DM	6	50	6.1	> 6	-
2	3/11/64	6	5	14	5.9	0.3	0.2
		8	3	14	2.8	0.5	0.3
		DM	5	40	4.8	0.3	0.2
3	3/15/64	5	4	26	5.7	2	1
		7	4	26	5.8	1.5	0.8
		DM	4	78	6.0	> 6	-
4	3/24/64	6	6	18	5.9	0.1	0.1
		8	2	18	1.5	0.1	0.1
		DM	6	42	3.6	2	0.3
5	4/7/64	5	5	38	4.9	0.5	0.1
		7	3	38	3.0	0.3	0.1
		DM	5	126	6.0	3	0.3
6	4/14/64	6	4	36	6.0	0.1	0.1
		8	4	36	5.5	0.1	0.1
		DM	4	139	6.0	0.1	0.1

TABLE II (Contd.)

Run. no.	Starting date	Filter no.	Rate gpm/ft^2	Length run, hr.	Final head loss, ft.	Turbidity, J.u.	
						Max.	Avg.
7	4/29/64	5	2	23	26	0.4	0.1
		7	6	23	6.0	0.1	0.1
		DM	6	46	5.0	0.3	0.2
8	5/5/64	6	3	38	4.5	0.1	0.1
		8	5	38	5.7	0.1	0.1
		DM	5	24	1.6	0.3	0.1

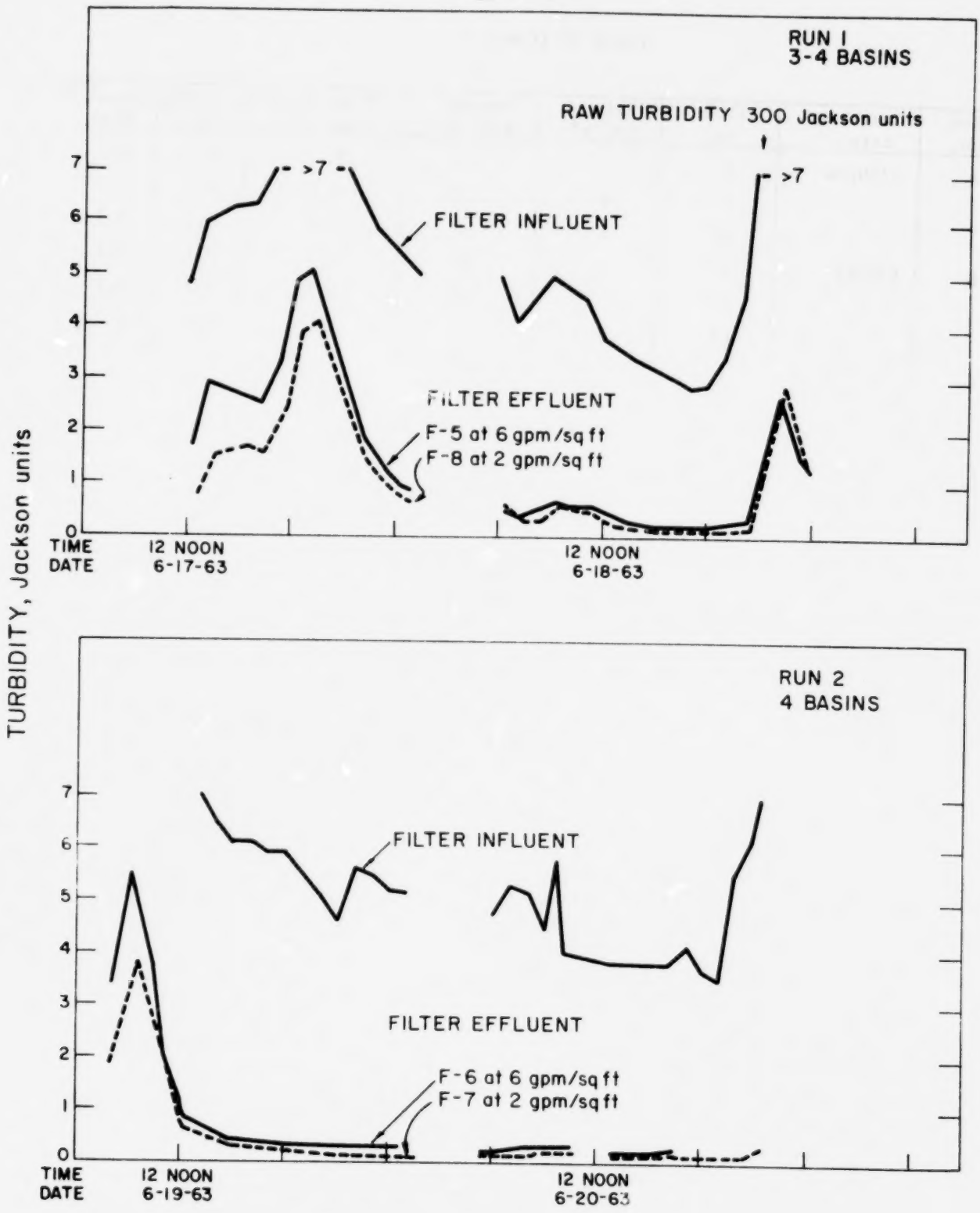

Figure 4. Turbidity values for runs I and 2 of summer season.

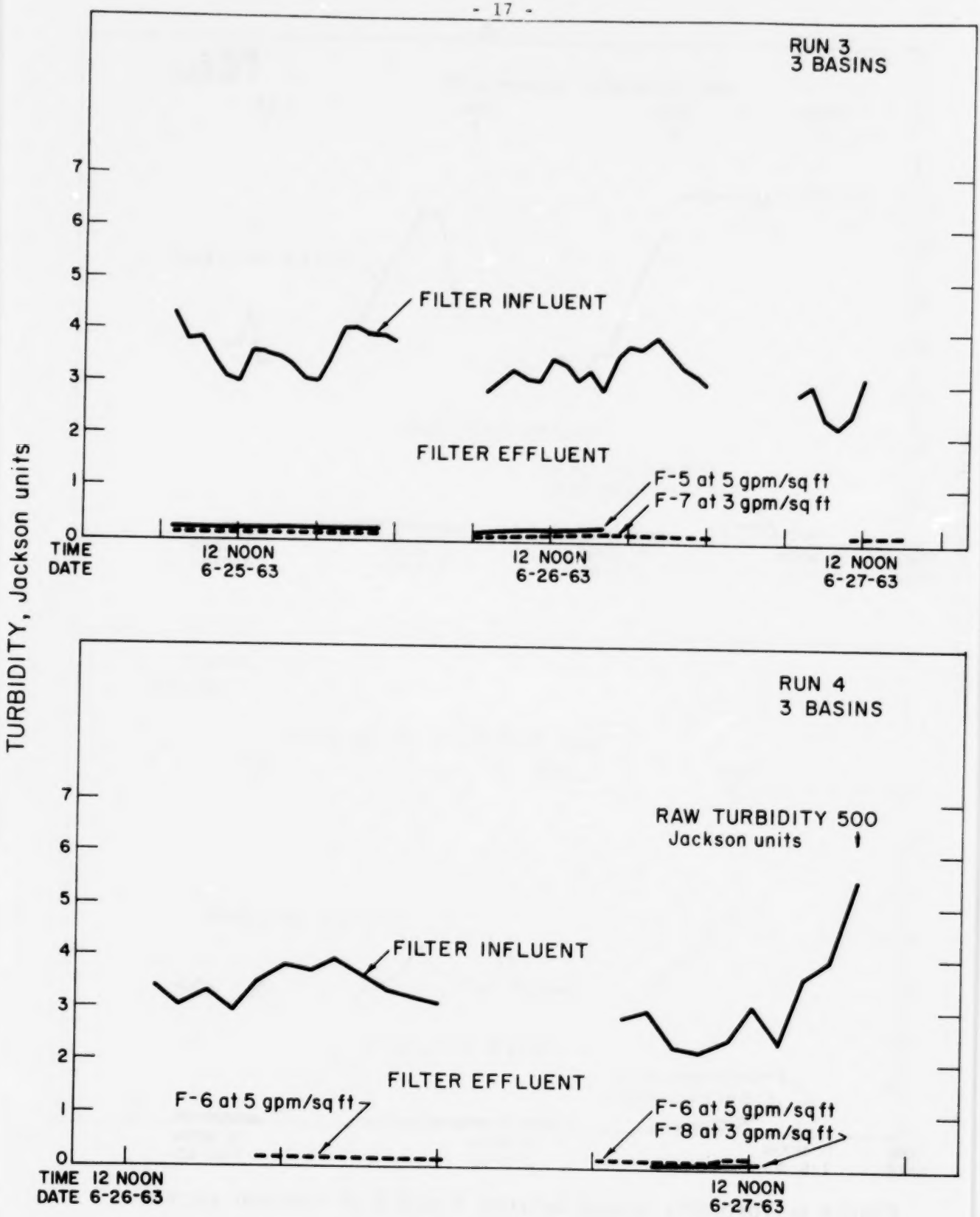

Figure 5. Turbidity values for runs 3 and 4 of summer season.

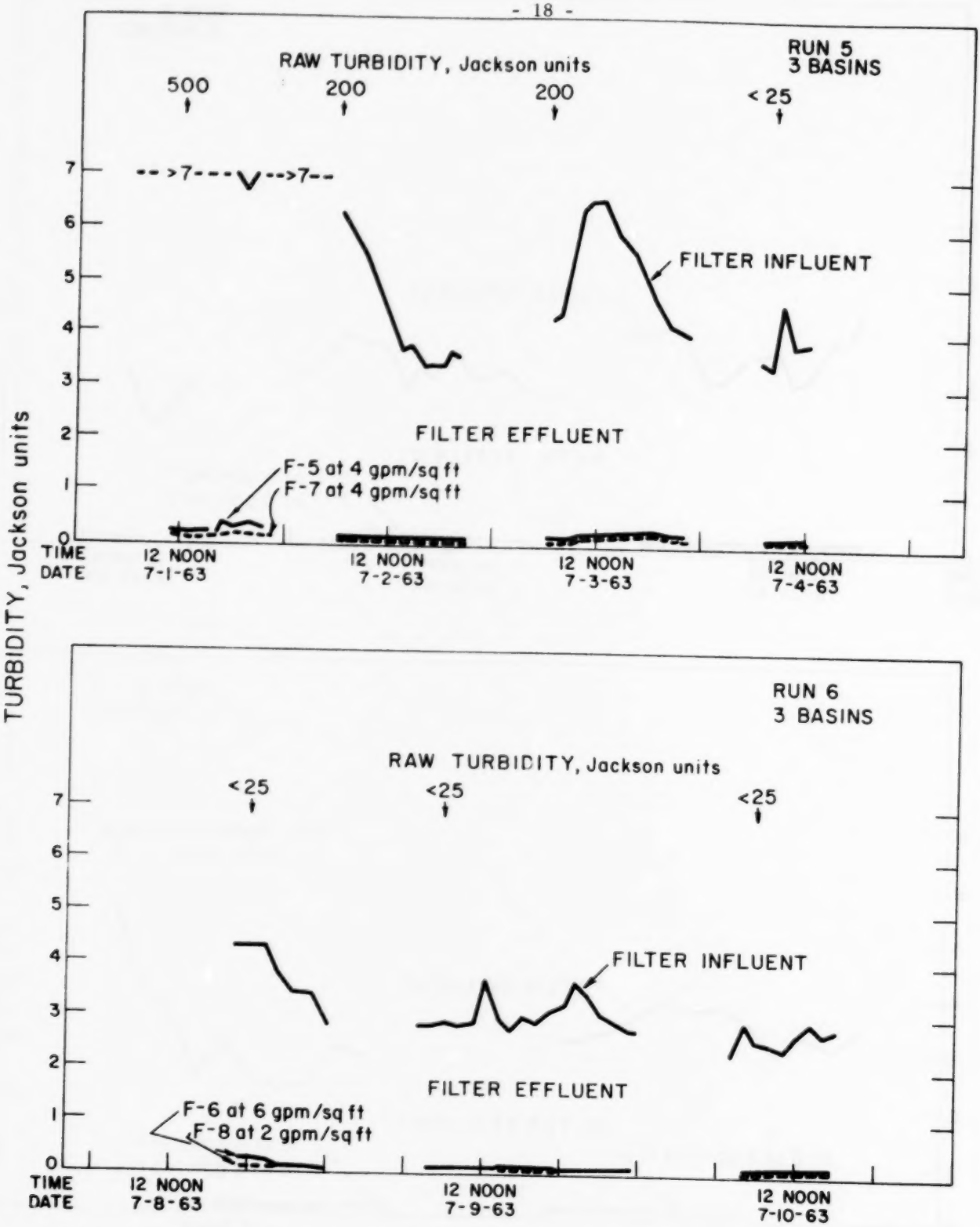

Figure 6. Turbidity values for runs 5 and 6 of summer season.

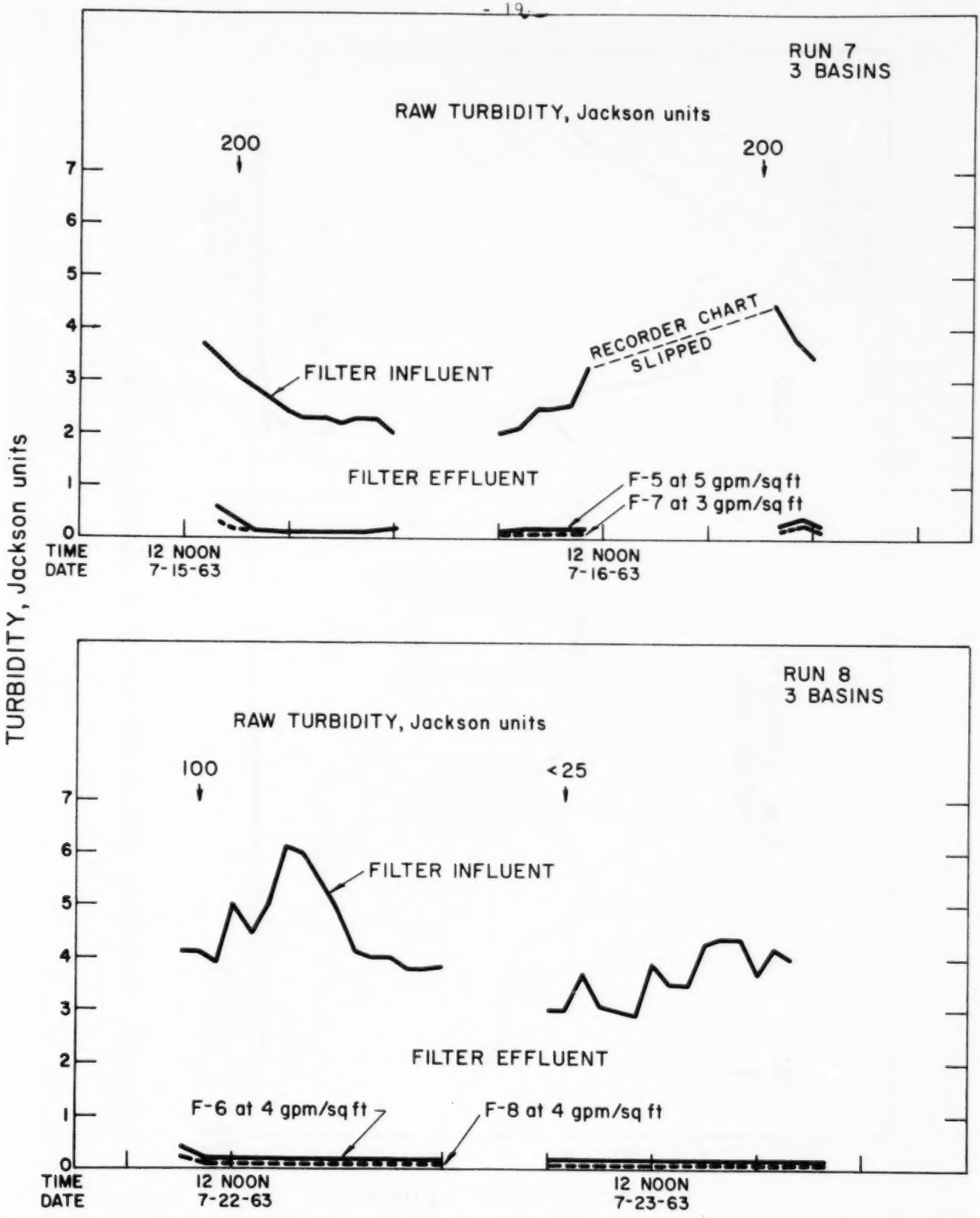

Figure 7. Turbidity values for runs 7 and 8 of summer season.

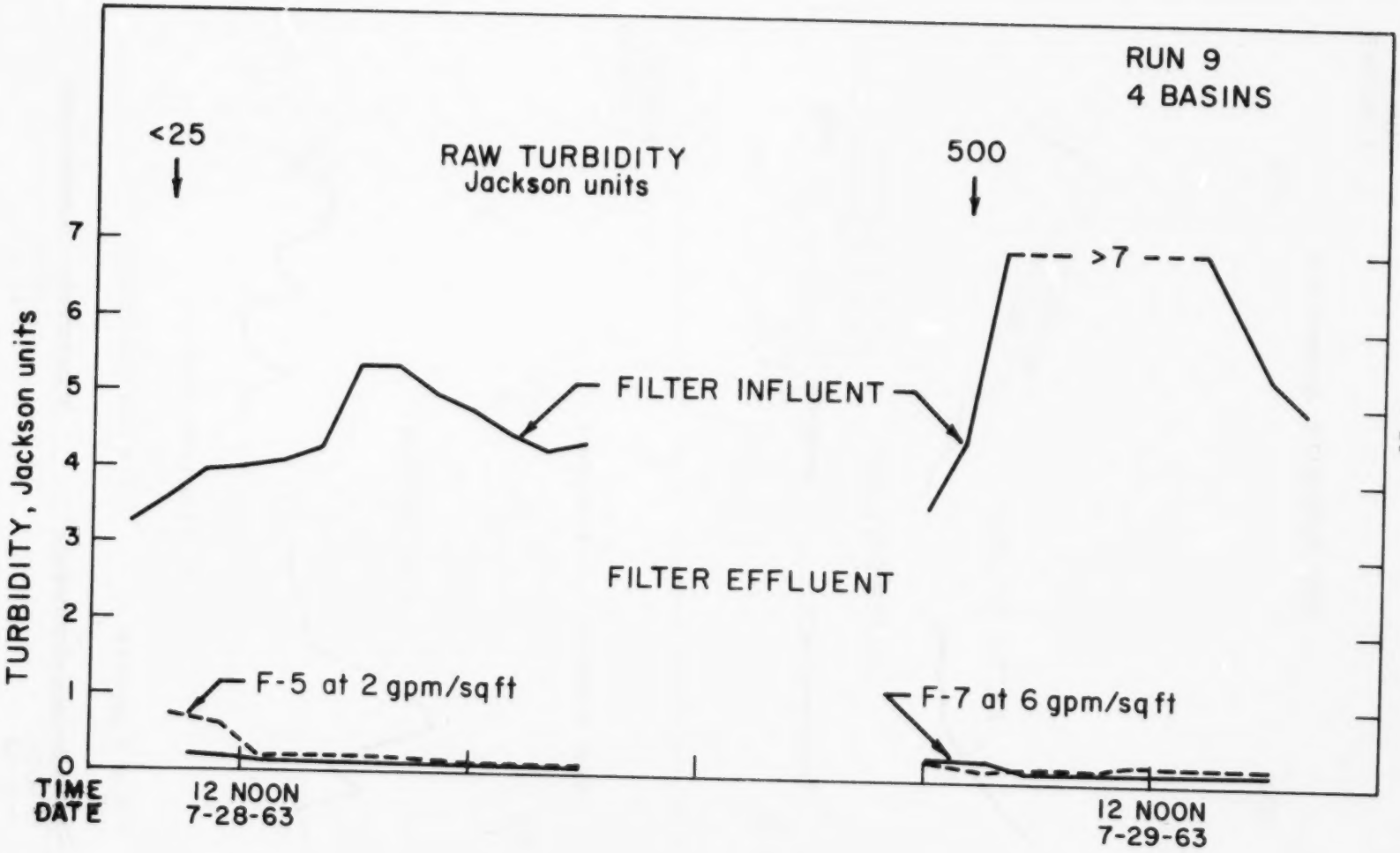

Figure 8. Turbidity values for run 9 of summer season.

During the subsequent runs, 3 through 9, the filter effluent turbidity was less than 1 Jackson unit (J.u.) and was generally below 0.5 J.u. regardless of the filter influent turbidity. Apparently the high filter influent turbidities experienced in the latter runs resulted from settling-basin upsets rather than inadequate coagulation since the material was readily filtered.

In the fall series of nine runs, illustrated in Figures 9 through 13, the effluent turbidities of both the settling basins and the filters were relatively low and stable except for the latter part of run 8 and all of run 9. At this troublesome period, unexpected stoppages of the raw water pumps resulted in a fluctuating water level in the settling basins. The pump problems coupled with constant chemical feeds allowed high turbidities and some color to pass onto and through the filters. In the first seven runs, the filter effluent turbidity was generally below 0.5 J.u. regardless of the filtration rate, which was varied from 2 to 6 gpm per square foot.

The winter series of ten runs is illustrated in Figures 14 through 23. The effluent turbidity and the incremental head-loss development for the small dual-media filter, which was installed before the start of the winter series, are shown on each of the figures. Variations in filtration rate on the full-scale sand filters had no appreciable effect on the effluent turbidity. Both filters produced water with a turbidity less than 1 J.u. during runs 1,2,3,5,8, and 10. During the other four runs there were periods when the effluent turbidity varied between 1 and 4 J.u. This was attributed to inadequate treatment of the water before filtration. The filter influent turbidity was higher during the winter series than either of the previous test periods; this resulted in shorter filtration runs. Except for runs 4 and 5 when pumping difficulties occurred, this poor basin effluent could be attributed to inefficient settling

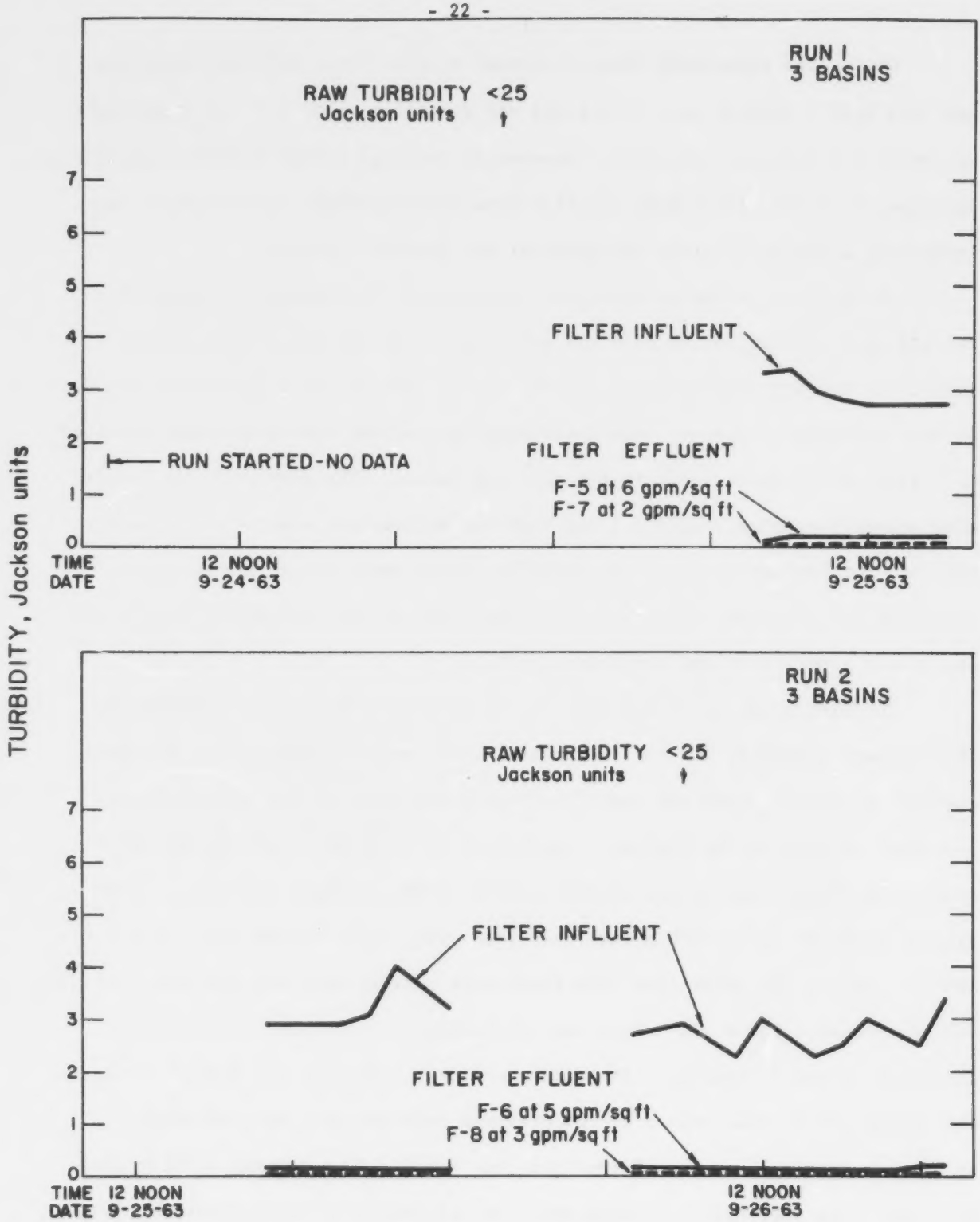

Figure 9. Turbidity values for runs 1 and 2 of fall season.

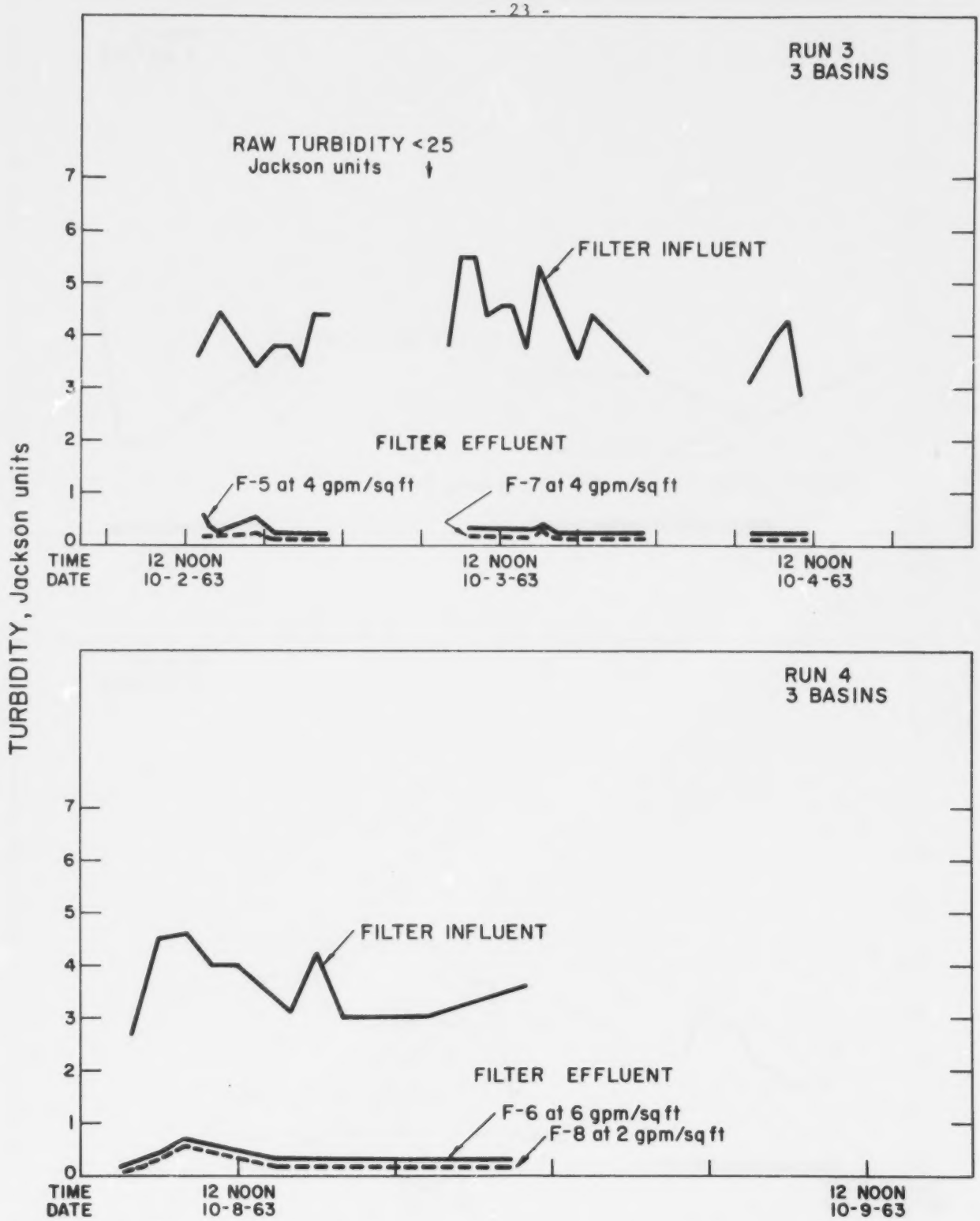

Figure 10. Turbidity values for runs 3 and 4 of fall season.

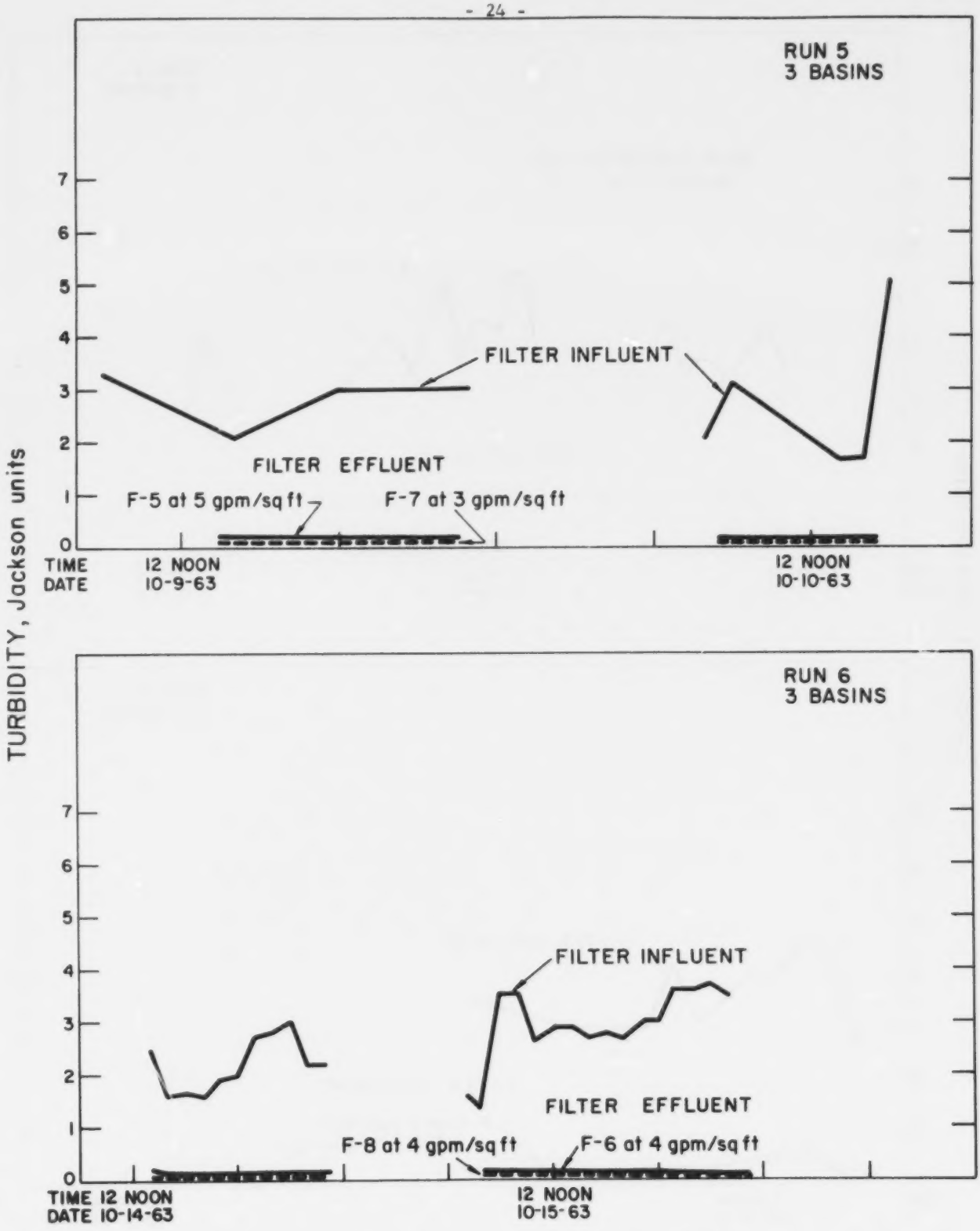

Figure II. Turbidity values for runs 5 and 6 of fall season.

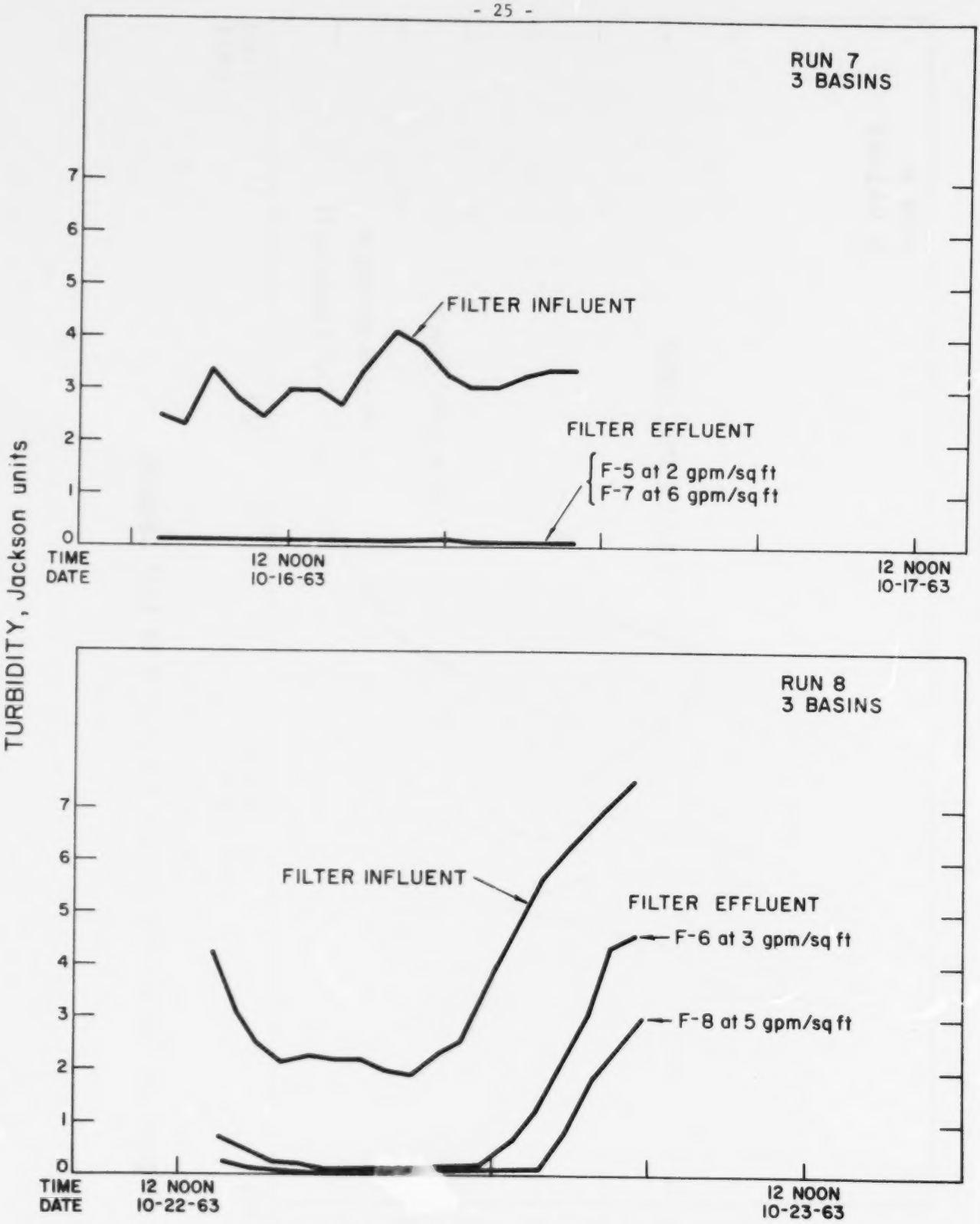

Figure 12. Turbidity values for runs 7 and 8 of fall season.

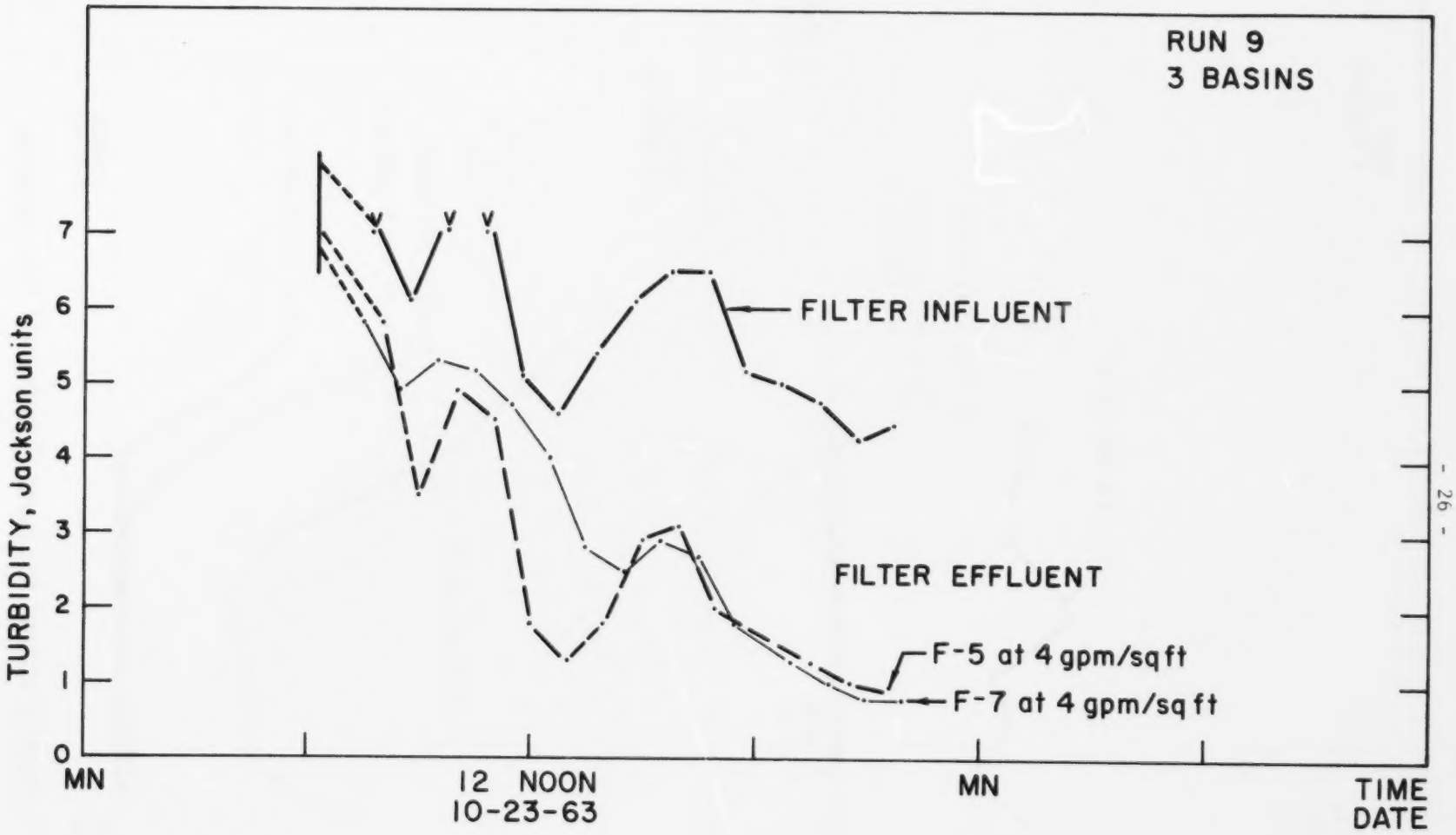

Figure 13. Turbidity values for run 9 of fall season.

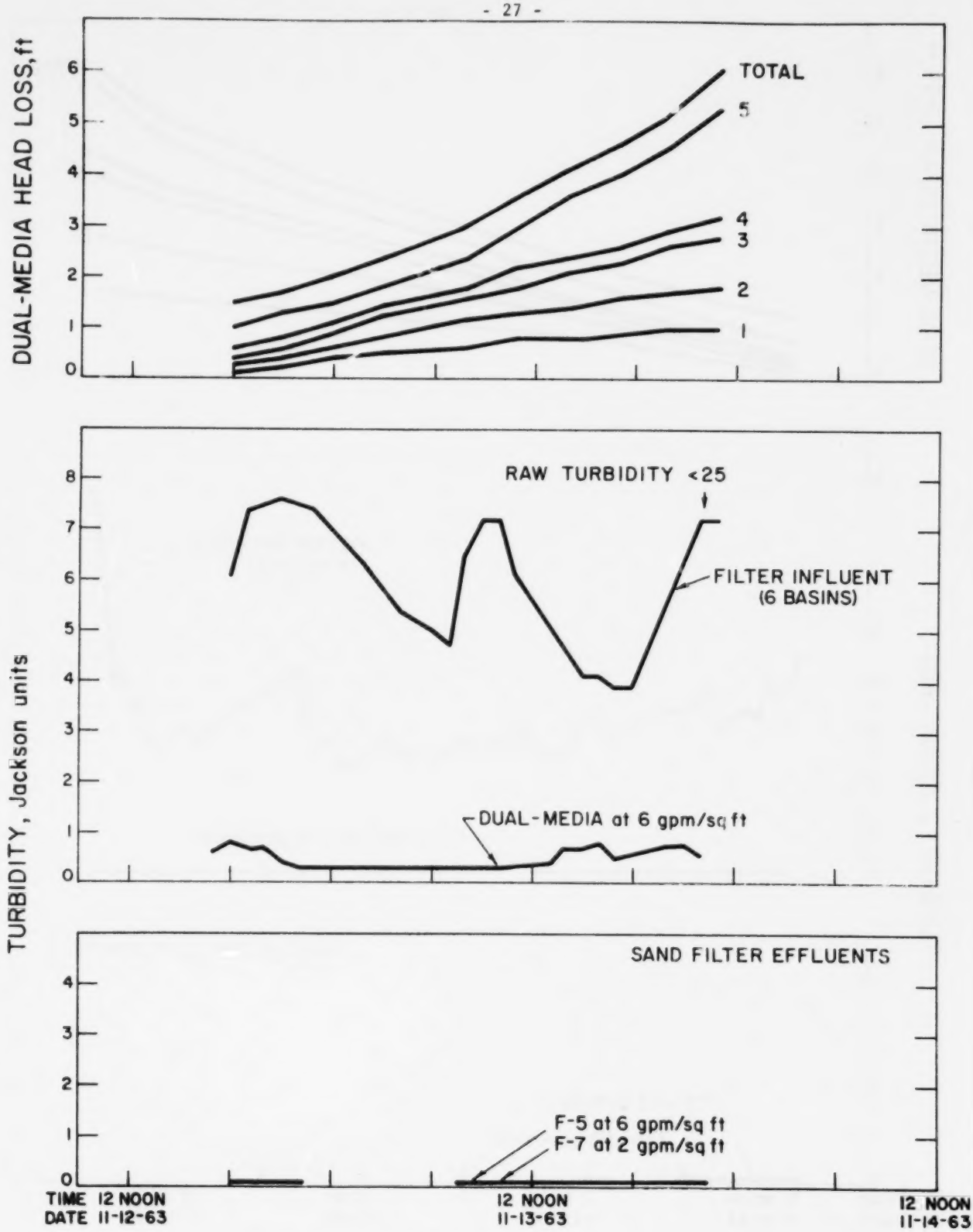

Figure 14. Head loss and turbidity values for run 1 of winter season.

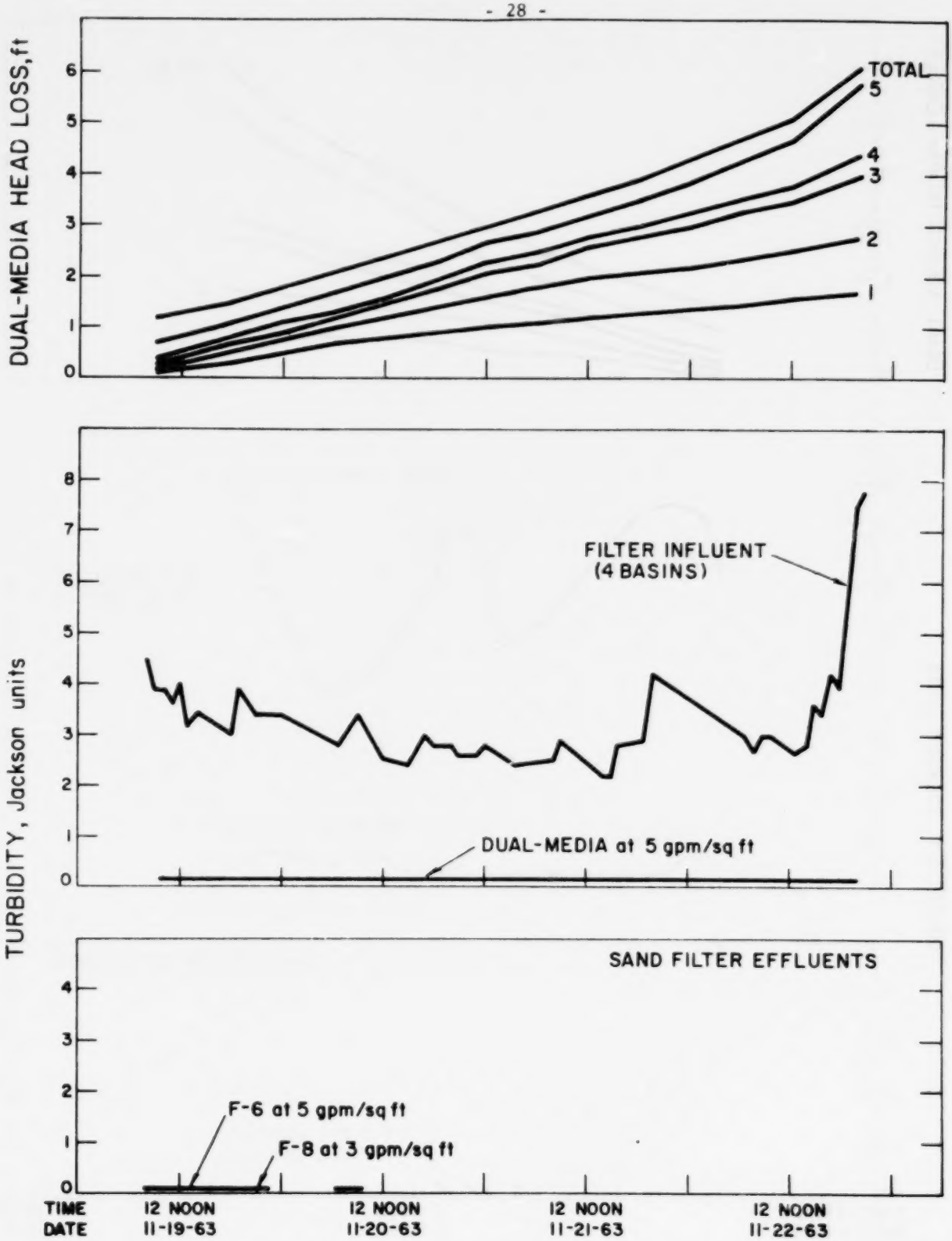

Figure 15. Head loss and turbidity values for run 2 of winter season.

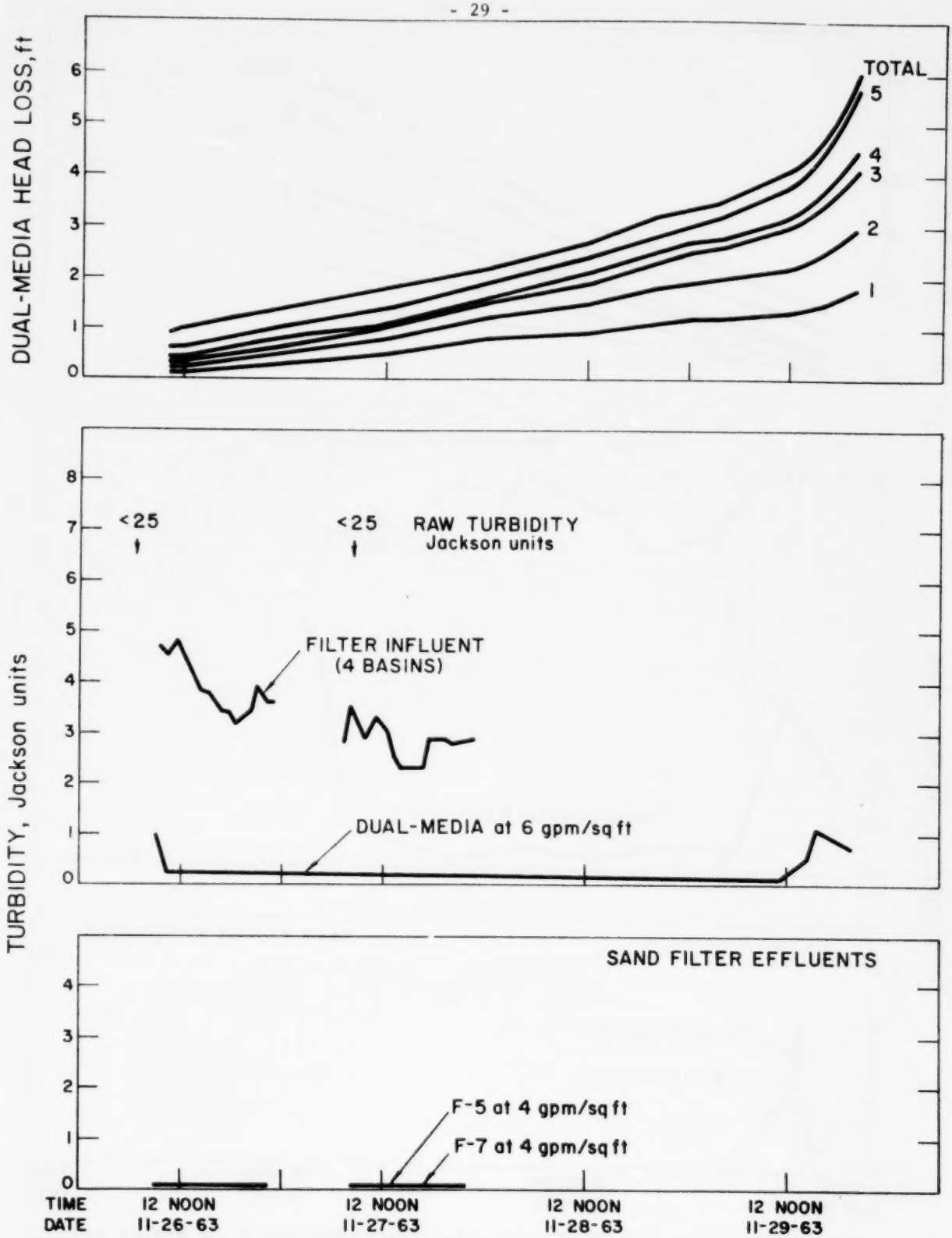

Figure 16. Head loss and turbidity values for run 3 of winter season.

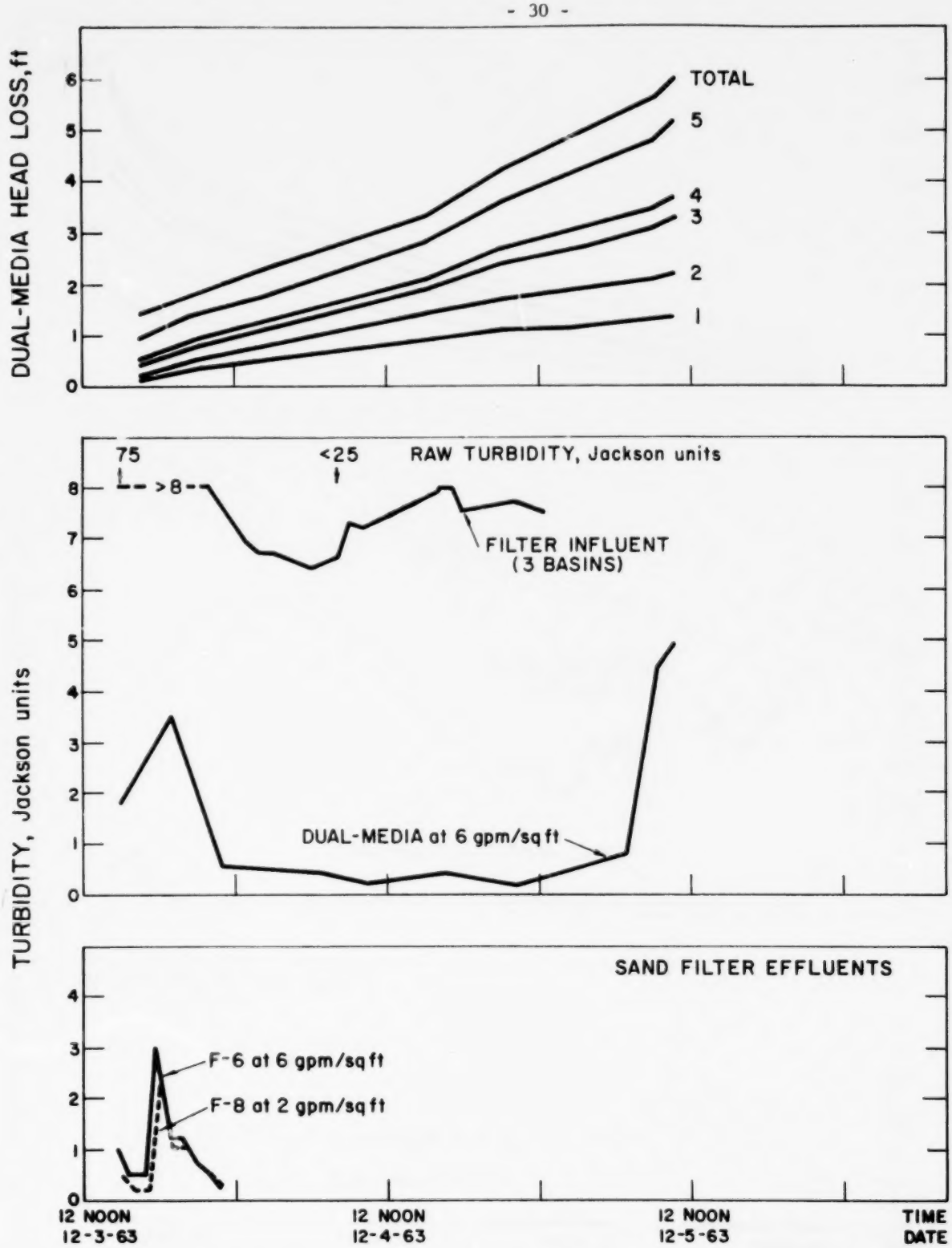

Figure 17. Head loss and turbidity values for run 4 of winter season.

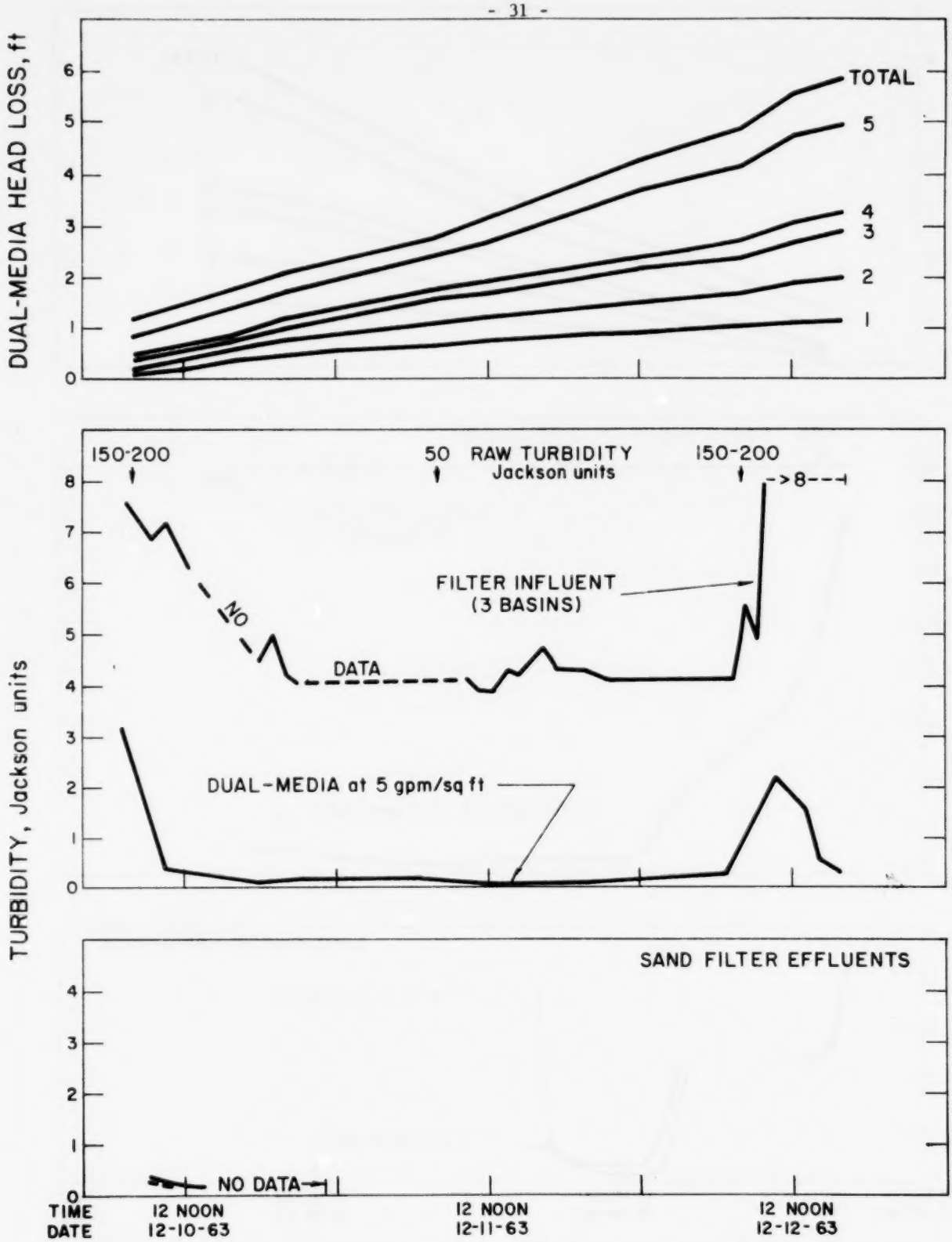

Figure 18. Head loss and turbidity values for run 5 of winter season.

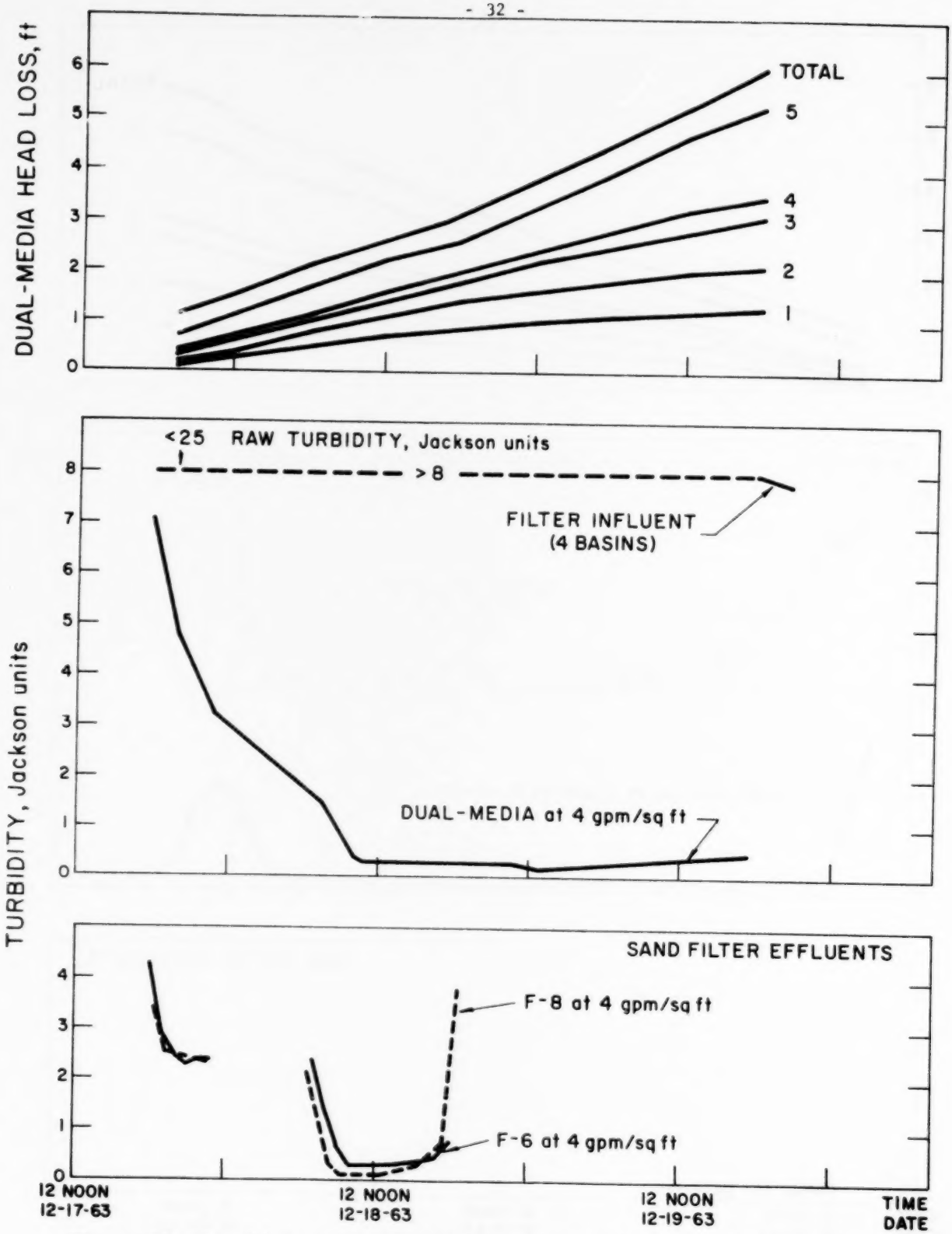

Figure 19. Head loss and turbidity values for run 6 of winter season.

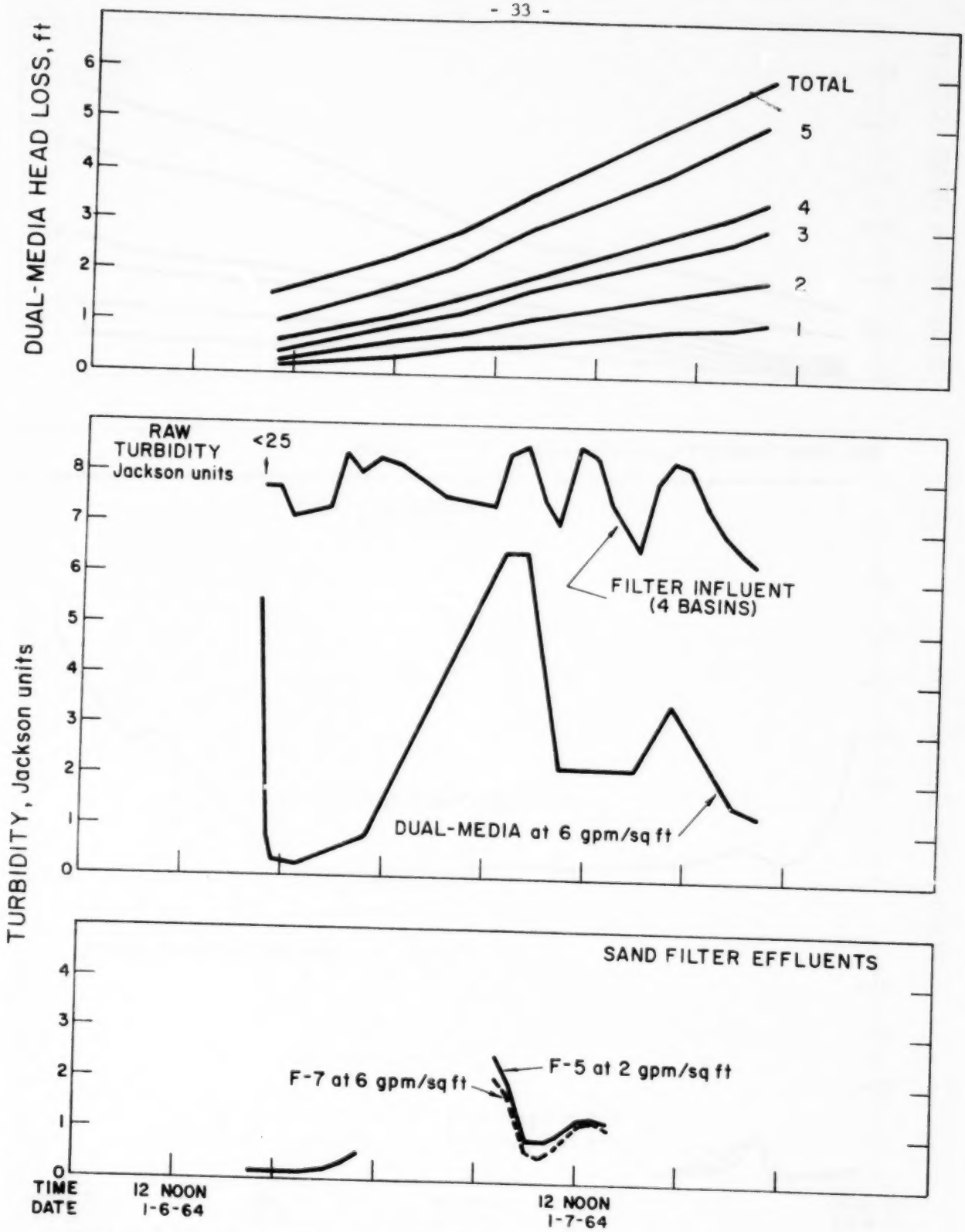

Figure 20. Head loss and turbidity values for run 7 of winter season.

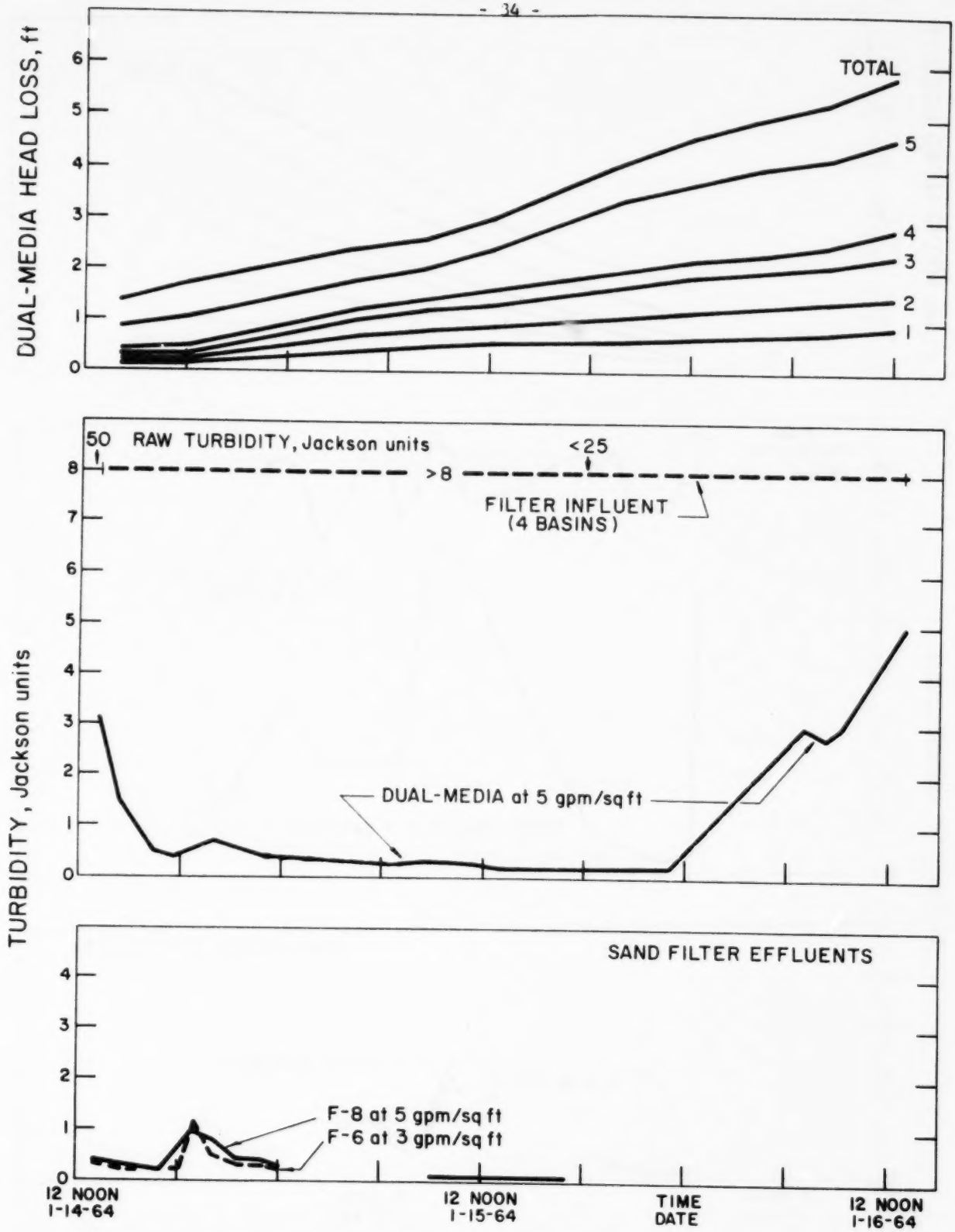

Figure 21. Head loss and turbidity values for run 8 of winter season.

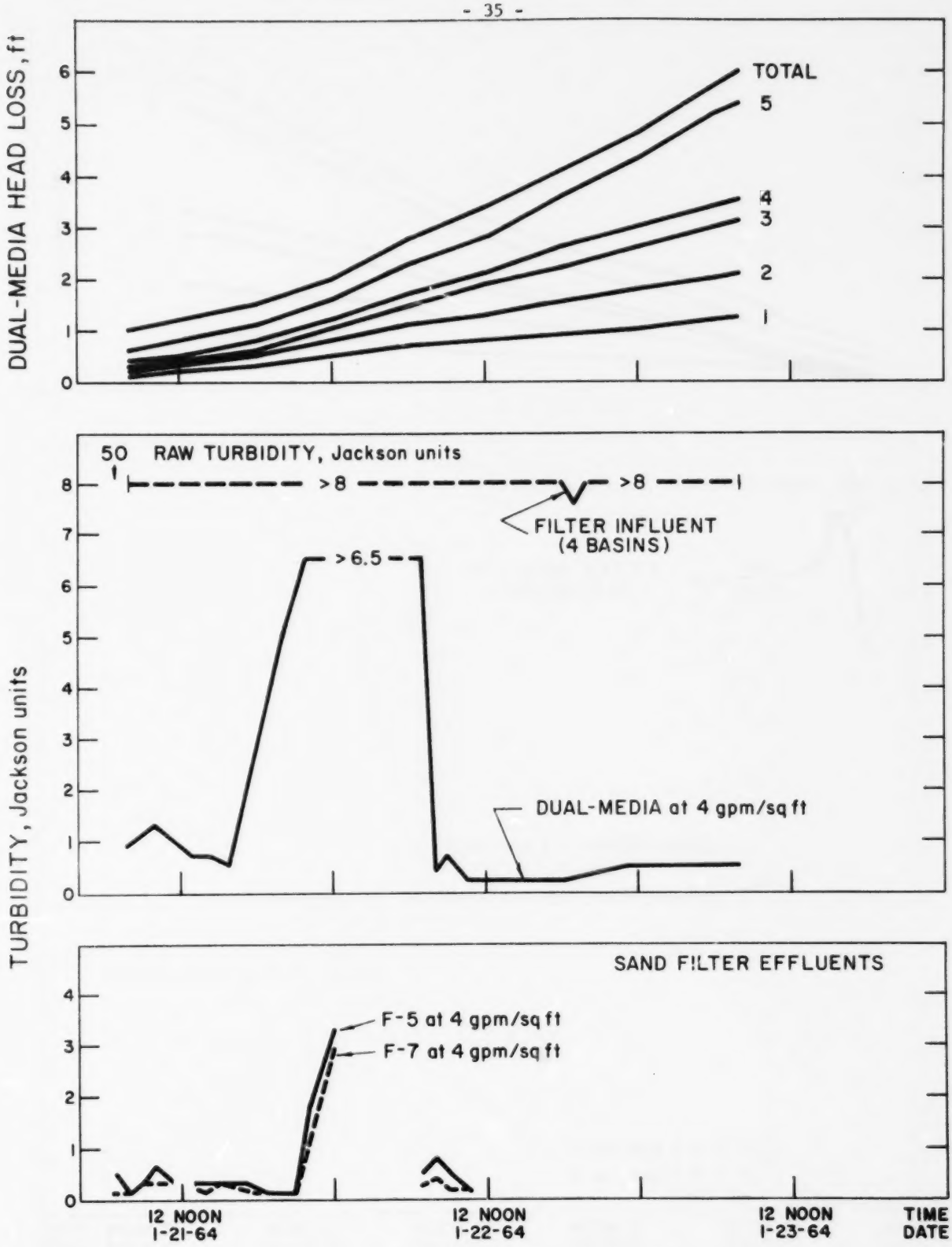

Figure 22. Head loss and turbidity values for run 9 of winter season.

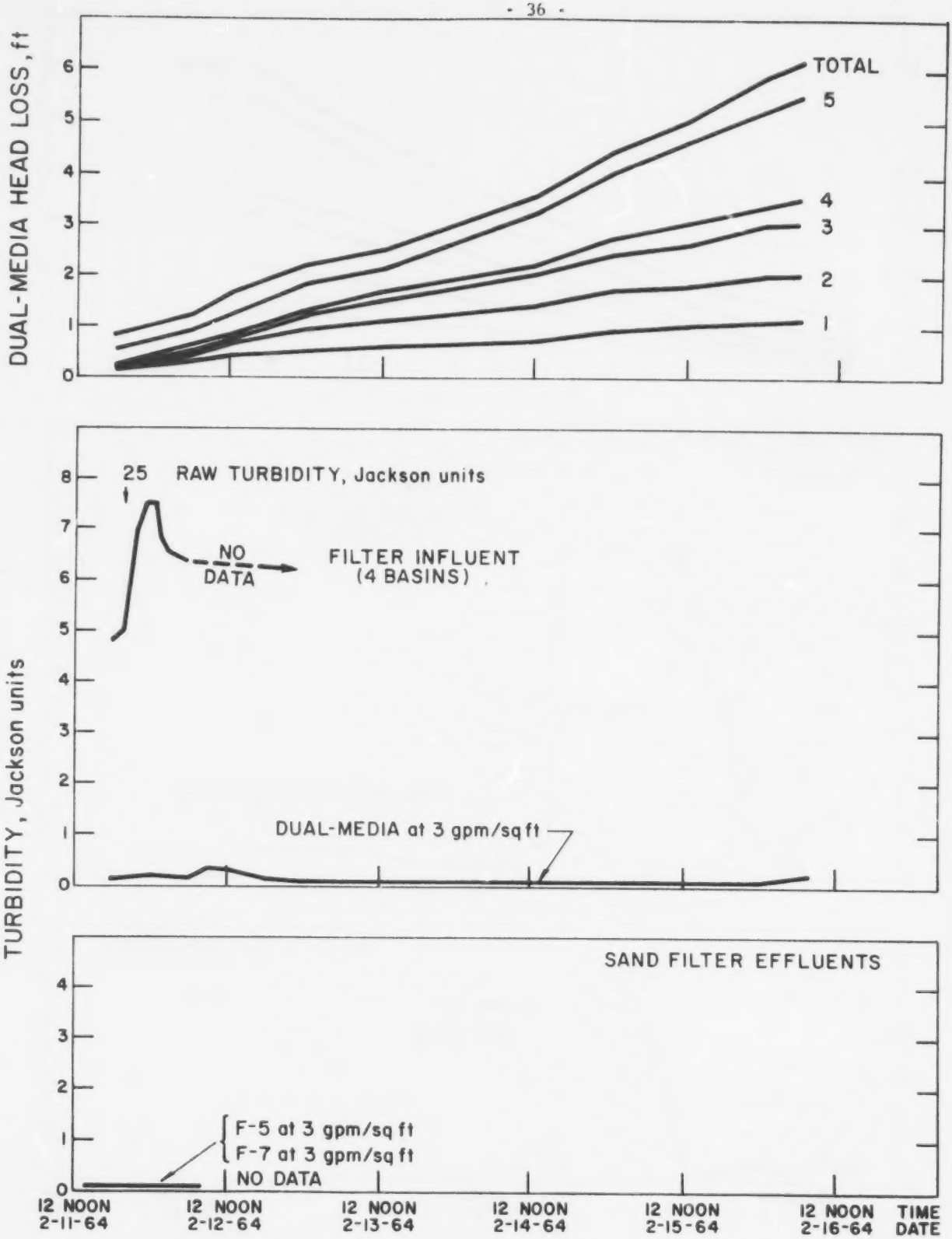

Figure 23. Head loss and turbidity values for run 10 of winter season.

which was due to the increase in viscosity and the hydraulic overloading of the sedimentation basins. During comparable periods, the dual-media filter produced water similar in quality to that of the sand filter operated at the same filtration rate. In runs 7 and 9, the breakthrough periods of the dual-media filter were more exaggerated in both magnitude and duration than those of the sand filter. Possible explanations for these differences include more sensitive measurement of the dual-media effluent turbidity, loss of the relative calibration of the turbidimeters, and a floc strength that was less adequate for the coarser media of the dual-media filter than it was for the sand filter.

During the spring series of eight runs, Figures 24 through 31, the basin effluent was highly turbid in runs 1,3,5, and 7. An apparent ineffective coagulation of the highly turbid raw water resulted in filter effluent turbidities greater than 1 J.u. for the sand filters during runs 1 and 3. In runs 5 and 7 as well as in the rest of the series, the filter effluent turbidity remained low; the high filter influent turbidities were due to poor settling rather than inadequate coagulation. Once again, variations in filtration rate had no appreciable effect on filter effluent turbidity. The dual-media filter generally produced water of a quality comparable to that of the sand filters during the same period of operation. In the latter part of the first run, even after the settling basin effluent started to improve, the dual-media filter effluent was poor because of the amount of un-coagulated material in the filter. It would have performed better if it had been backwashed and restarted on the morning of March 5. The head-loss data also show the presence

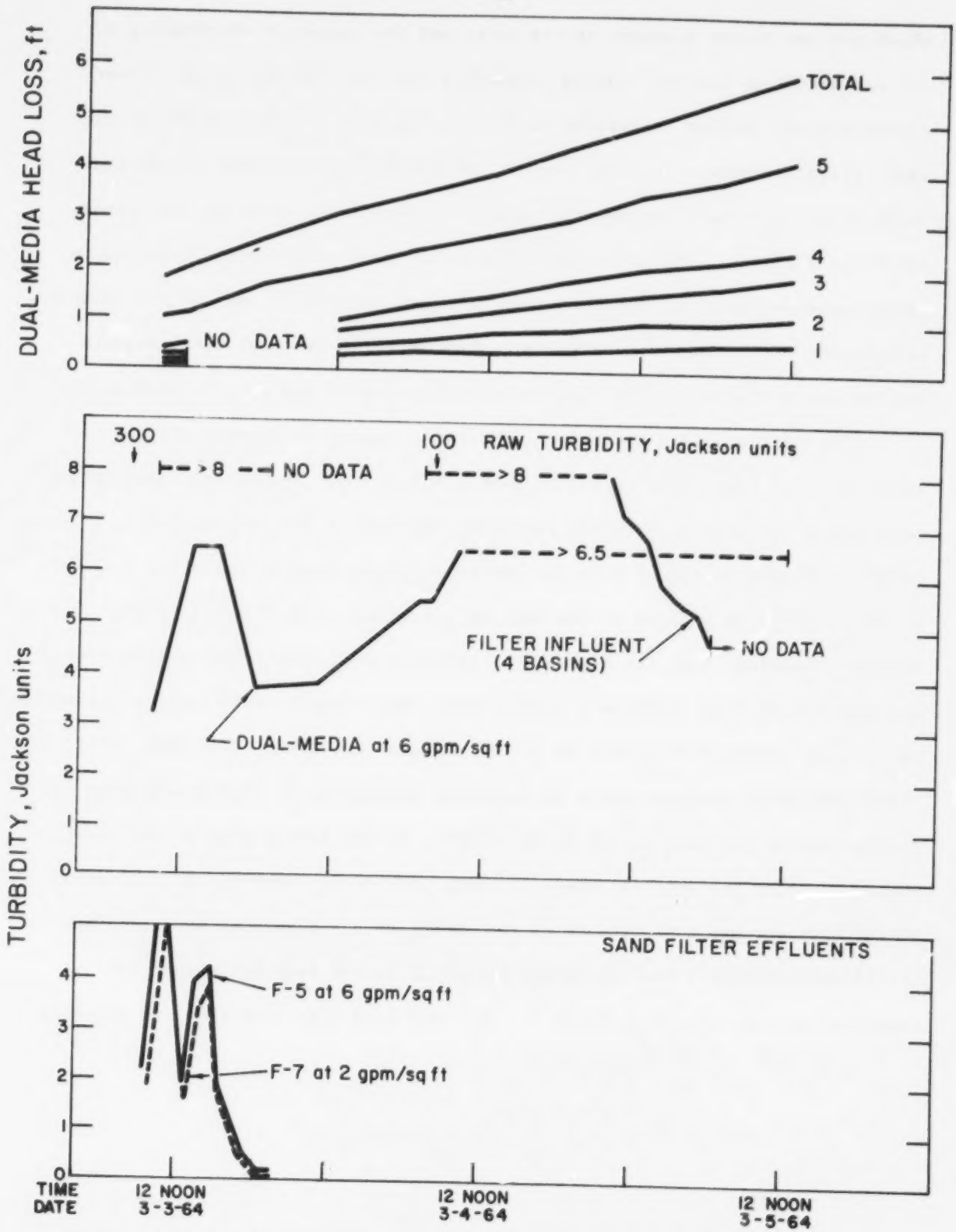

Figure 24. Head loss and turbidity values for run I of spring season.

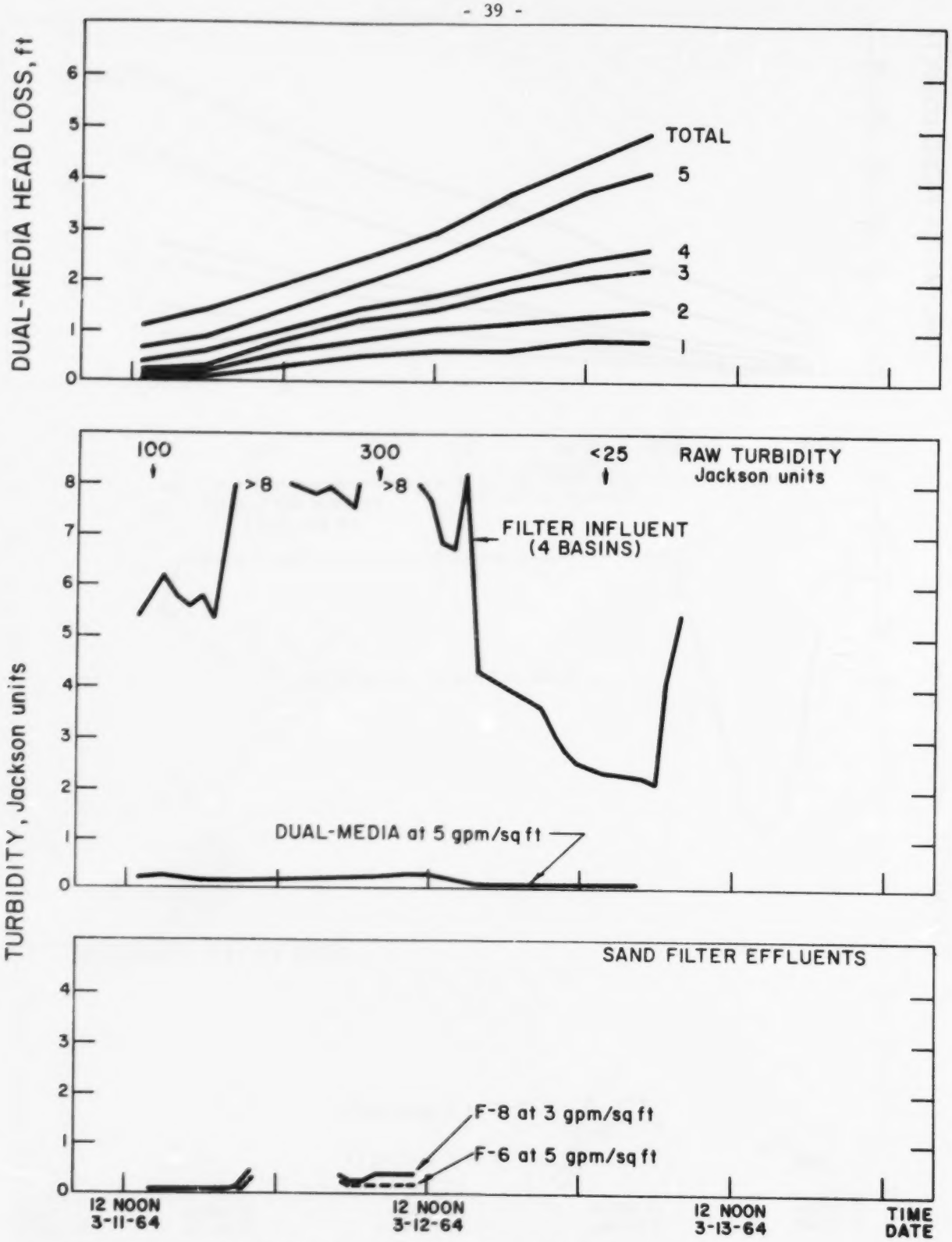

Figure 25. Head loss and turbidity values for run 2 of spring season.

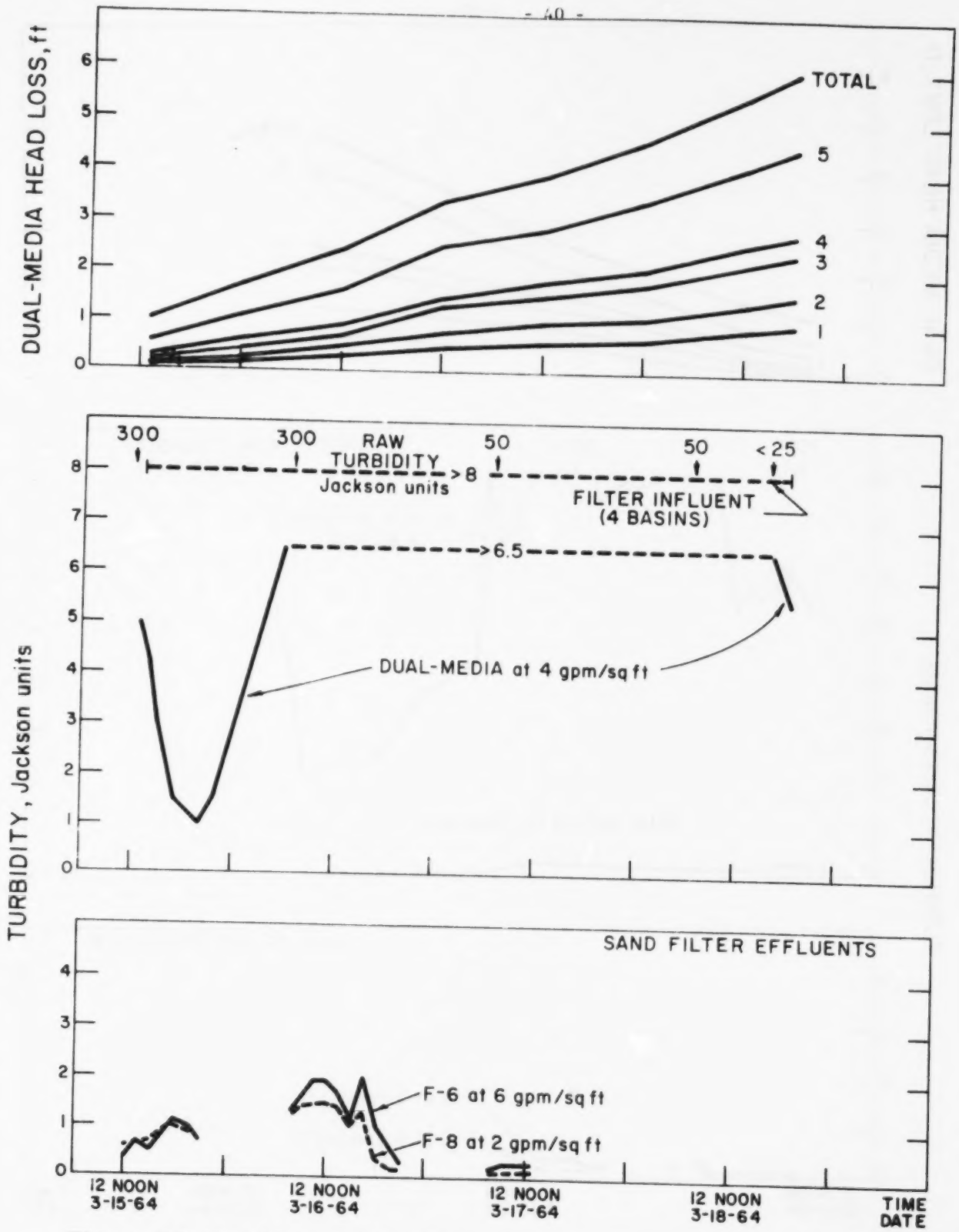

Figure 26. Head loss and turbidity values for run 3 of spring season.

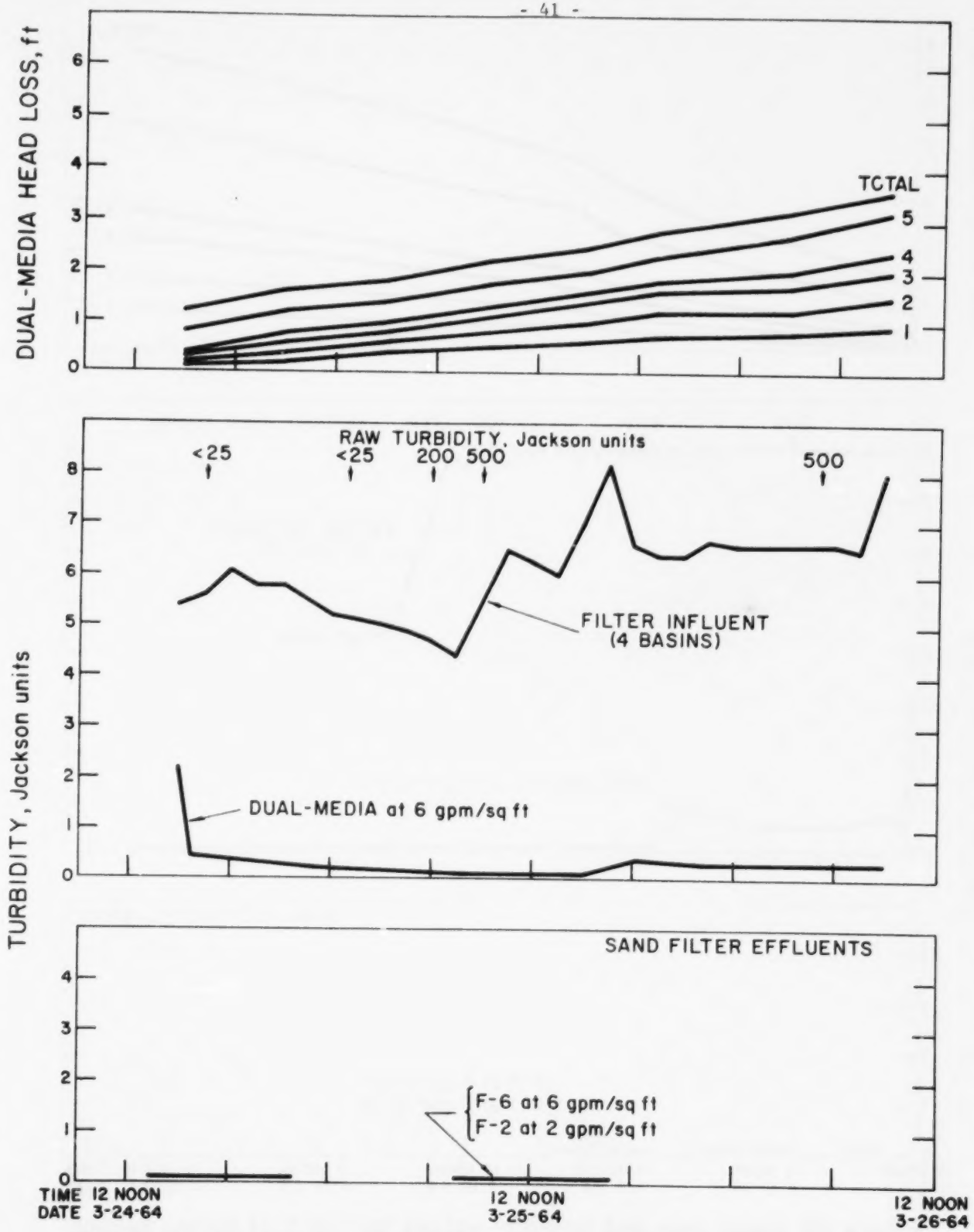

Figure 27. Head loss and turbidity values for run 4 of spring season.

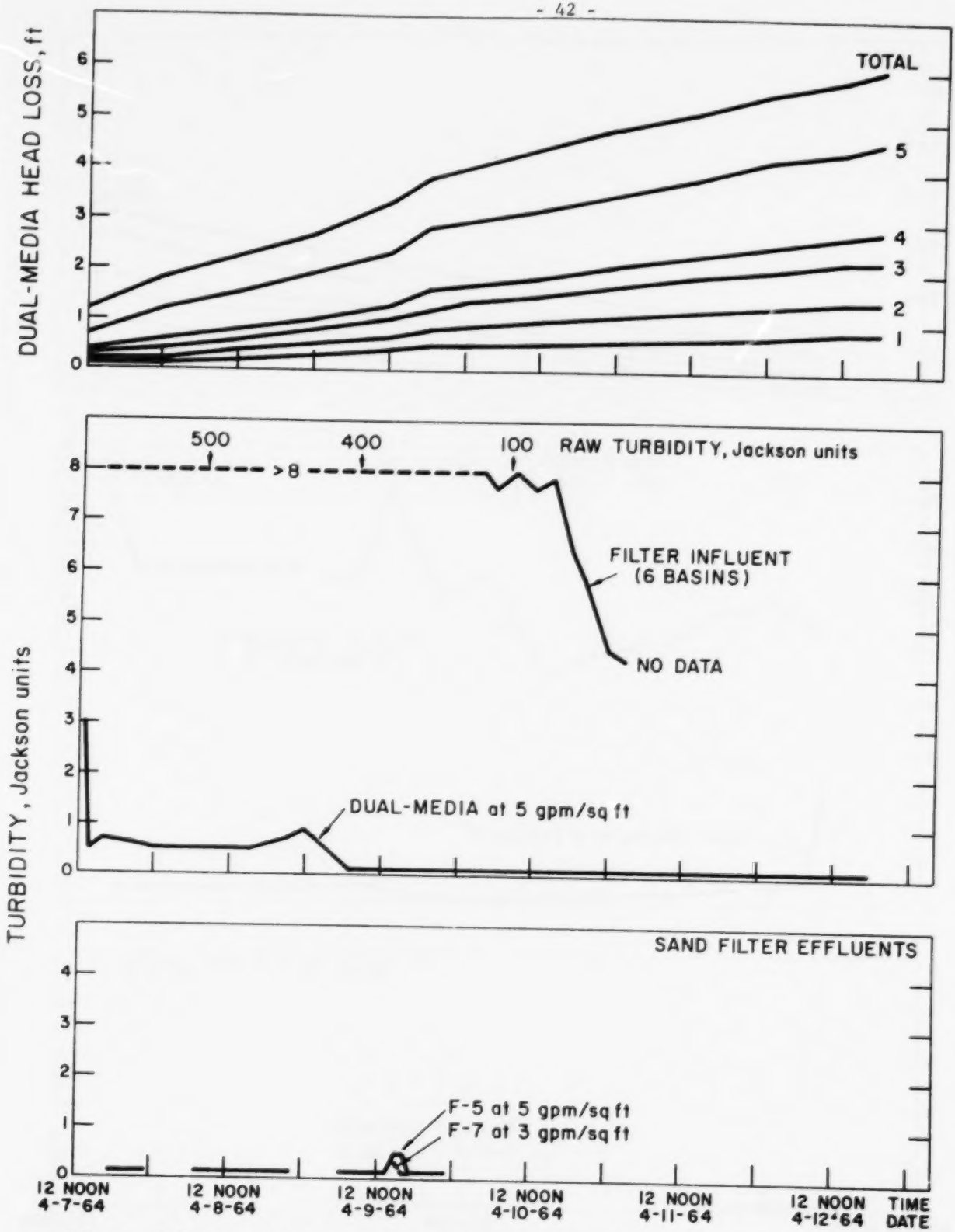

Figure 28. Head loss and turbidity values for run 5 of spring season.

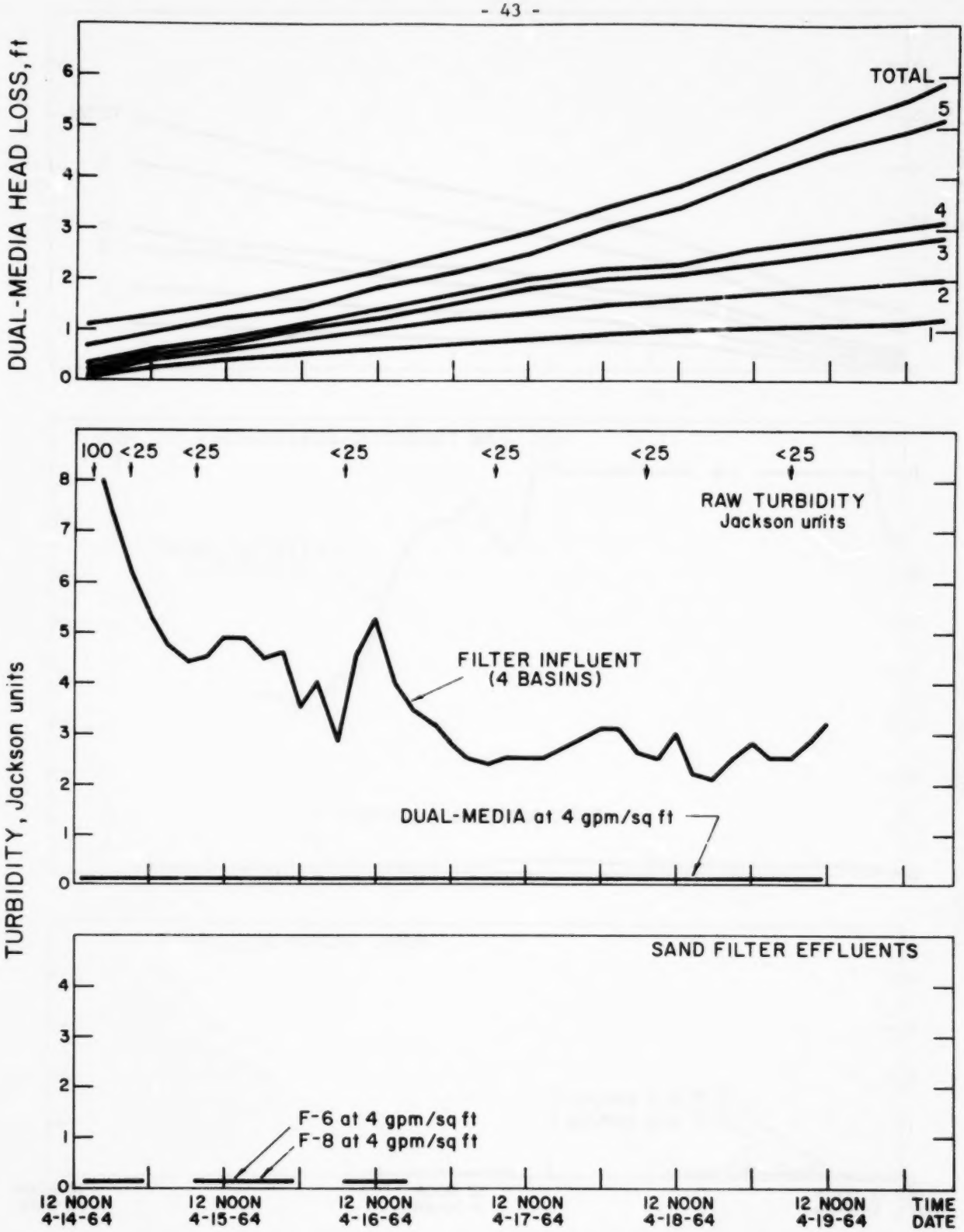

Figure 29. Head loss and turbidity values for run 6 of spring season.

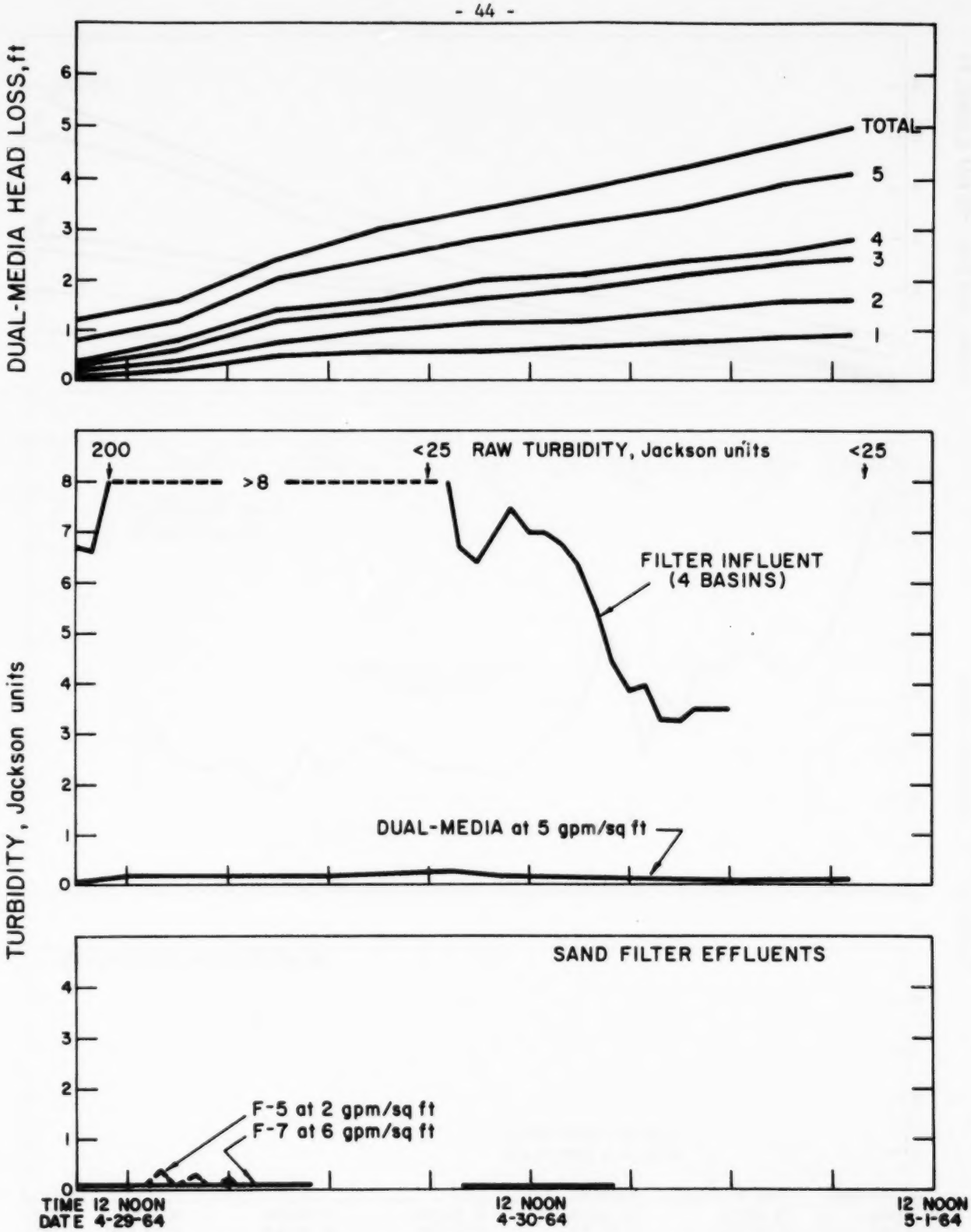

Figure 30. Head loss and turbidity values for run 7 of spring season.

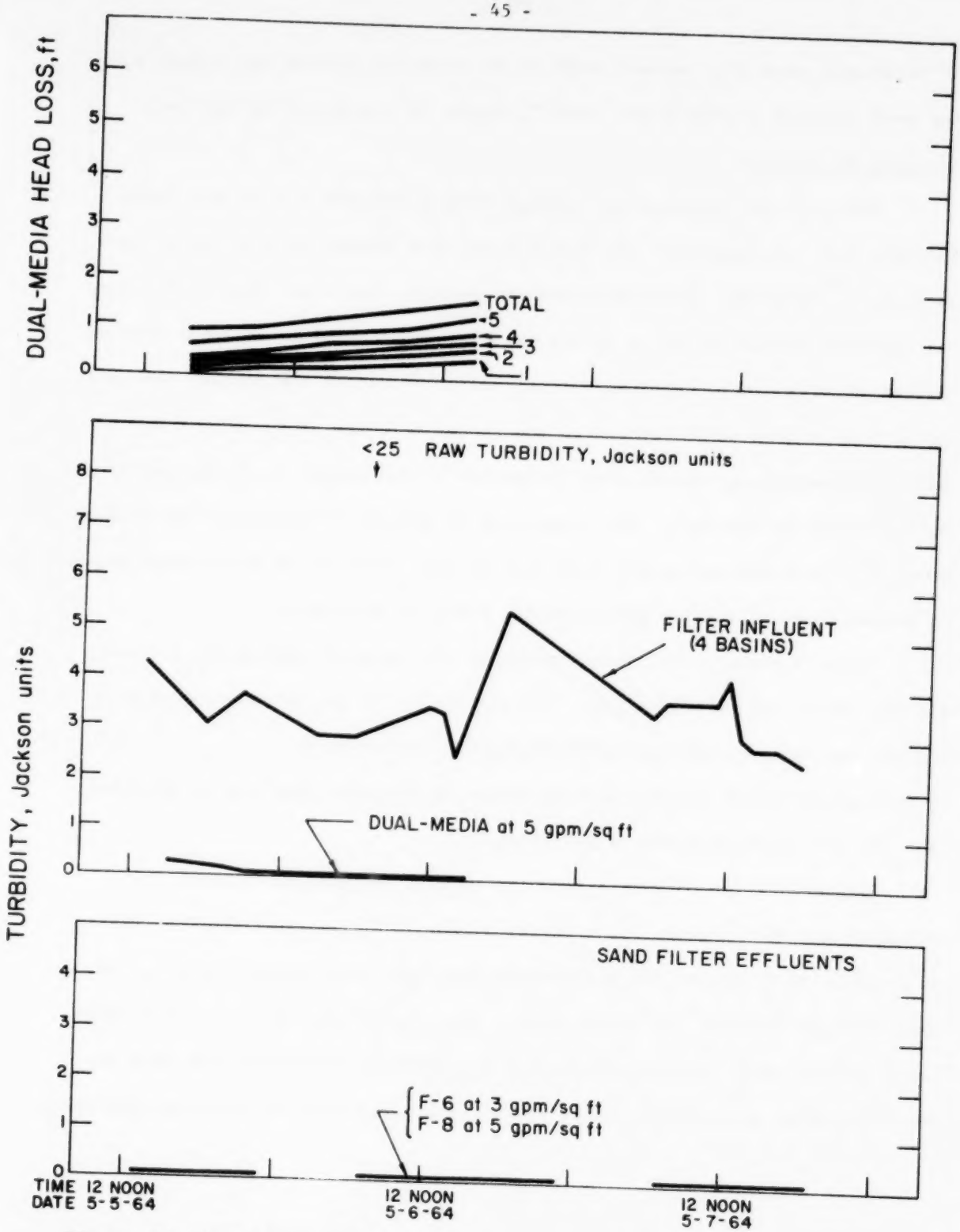

Figure 31. Head loss and turbidity values for run 8 of spring season.

of relatively weak floc because most of the material removed was lodged in the sand (between points 4 and "total", Figure 3) instead of in the coal.

Coliform Penetration

The coliform loadings and passage through the plant units are shown in Table III. A summary of the data for the four series of sand filter runs is shown in Table IV. These data show an average consistent plant efficiency for coliform removal of 98 to 99 percent throughout the four seasonal periods without chlorination. Coliform removal efficiencies for the filter, however, varied from a high of 94 percent in the winter to a low of 81 percent in the fall. Sedimentation removed from 72 percent in the summer to 92 percent of the coliforms in the fall. The comparison of removal efficiencies for filtration rates of 2 to 6 gpm per square foot reveals that there is no significant degradation in bacteriological quality due to higher rates of filtration.

Table V compares coliform removal by the sand and dual-media filters for the winter and spring series. The similarity of the percent removals for the two types of filters substantiates the claim that an effluent of equal quality with no change in chemical feed can be obtained with the use of the dual-media modification.

Figures 32 and 33 show a definite lack of correlation between the turbidity and the coliform count of the filter influent and effluent. The great majority of the coliform determinations were made without notation of time, thereby limiting the usable data. Also the determinations do not cover a wide enough range because the samples for coliform determinations were not taken during an appreciable number of filter breakthrough or settling tank upsets.

TABLE III

COLIFORM LOADING AND PASSAGE

	Coliforms/100 ml		Sand filter effluent						Dual-media effluent	
Date	Plant influent	Filter influent	Filter no.	Rate, gpm/ft^2	Coliforms/ 100 ml	Filter no.	Rate, gpm/ft^2	Coliforms/ 100 ml	Rate, gpm/ft^2	Coliforms/ 100 ml
6/17/63	3,000	2,300	5	6	110	7	2	65		
6/18/63	500	-	5	6	< 1	7	2	5		
6/19/63	2,500	500	6	6	5	8	2	8		
6/20/63	2,600	400	6	6	2	8	2	3		
6/21/63	4,000	2,000	6	6	4	8	2	1	NOT	
6/25/63	800	600	5	5	3	7	3	2		
6/26/63	1,200	400	5	5	2	7	3	4		
6/27/63	1,000	100	5	5	2	7	3	2		
7/1/63	3,600	400	5	4	100	7	4	200	IN	
7/2/63	2,600	100	5	4	6	7	4	4		
7/3/63	1,000	25	5	4	3	7	4	5		
7/4/63	700	50	5	4	3	7	4	2		
7/8/63	1,200	700	6	6	200	8	2	150		
7/9/63	500	200	6	6	< 1	8	2	2		
7/10/63	1,000	400	6	6	10	8	2	4	OPERATION	
7/11/63	700	200	6	6	3	8	2	3		
7/15/63	2,300	200	5	5	40	7	3	25		
7/16/63	3,000	600	5	5	4	7	3	6		
7/22/63	1,000	< 1	6	4	< 1	8	4	< 1		
7/23/63	800	< 1	6	4	< 1	8	4	< 1		
7/28/63	1,200	< 1	5	2	< 1	7	6	< 1		
7/29/63	1,800	< 1	5	2	< 1	7	6	< 1		
9/24/63	3,500	< 100	5	6	5	7	2	2		
9/26/63	2,000	< 100	6	5	7	8	3	6		
10/2/63	1,500	500	5	4	250	7	4	200		
10/3/63	1,000	< 100	5	4	10	7	4	10		
10/4/63	1,200	100	5	4	12	7	4	15		
10/8/63	2,400	200	6	6	16	8	2	16		
10/9/63	1,000	10	5	5	7	7	3	5		

TABLE III (CONTD.)

	Coliforms/100 ml		Sand filter effluent						Dual-media effluent	
Date	Plant influent	Filter influent	Filter no.	Rate, gpm/ft^2	Coliforms/ 100 ml	Filter no.	Rate, gpm/ft^2	Coliforms/ 100 ml	Rate, gpm/ft^2	Coliforms/ 100 ml
10/10/63	1,500	20	5	5	10	7	3	10	NOT	
10/14/63	600	40	6	4	5	8	4	8		
10/15/63	3,100	800	6	4	25	8	4	25	IN	
10/16/63	1,200	80	6	2	8	8	6	10		
10/22/63	1,000	100	6	3	55	8	5	80	OPERATION	
10/23/63	1,800	150	5	4	15	7	4	18		
11/12/63	500	20	5	6	2	7	2	2	6	10
11/20/63	1,000	1	6	5	1	8	3	1	5	1
11/27/63	4,000	600	5	4	11	7	4	15	4	10
11/28/63	3,200	400	5	4	2	7	4	3	4	5
12/3/63	4,000	1,200	6	6	26	8	2	9	6	22
12/10/63	4,500	75	5	5	3	7	3	< 1	5	10
12/18/63	1,200	450	6	4	200	8	4	240	4	125
1/6/64	-	-	-	-	-	-	-	-	-	-
1/14/64	200	10	6	3	< 1	8	5	1	5	8
1/21/64	200	54	5	4	12	7	4	19	4	25
1/22/64	800	80	5	4	2	7	4	4	4	6
2/11/64	-	-	-	-	-	-	-	-	-	-
3/3/64	1,600	600	5	6	65	7	2	50	6	40
3/4/64	400	80	5	6	15	7	2	12	6	12
3/12/64	400	2	6	5	< 1	8	3	< 1	5	< 1
3/16/64	4,000	800	5	4	54	7	4	40	4	12
3/17/64	5,000	1,200	5	4	50	7	4	50	4	18
3/24/64	700	3	6	6	< 1	8	2	< 1	6	< 1
3/25/64	1,800	40	6	6	1	8	2	< 1	6	8
4/8/64	3,500	600	5	5	85	7	3	80	5	126
4/9/64	1,200	50	5	5	26	7	3	16	5	26
4/15/64	1,700	1	6	4	< 1	8	4	< 1	4	< 1
4/16/64	2,100	160	6	4	12	8	4	21	4	18
4/29/64	700	< 1	5	2	< 1	7	6	< 1	6	< 1
4/30/64	2,300	30	5	2	< 1	7	6	< 1	6	12
5/5/64	3,400	45	6	3	2	8	5	1	5	< 1
5/6/64	2,000	65	6	3	10	8	5	15	5	40

TABLE IV

COLIFORM REMOVAL FOR ALL TEST PERIODS

Coliforms/100 ml[a]			Filter effluent		% removal by		
Plant influent	Filter influent	Removal by sedimentation, %	Rate gpm/ft^2	Coliforms/ 100 ml	Filter	Plant	No. of Samples
			Summer series				
1,900	840	56	6	41	95	97.8	8
1,700	380	78	5	10	97	99.4	5
2,000	140	93	4	40	71	98.0	8
1,700	380	78	3	8	98	99.5	5
1,900	840	56	2	30	96	98.4	8
		72			91	98.6	
			Fall series				
2,400	130	95	6	10	92	99.6	3
1,400	70	95	5	26	63	98.1	4
1,500	280	81	4	50	82	96.7	12
1,400	70	95	3	19	73	98.6	4
2,400	130	95	2	9	93	99.6	3
		92			81	98.5	
			Winter series				
2,300	610	73	6	14	98	99.4	2
1,900	29	98	5	2	93	99.9	3
1,900	320	83	4	50	84	97.4	10
1,900	29	98	3	< 1	> 96	> 99.9	3
2,300	610	73	2	6	99	99.7	2
		85			94	99.3	
			Spring series				
1,300	130	90	6	13	90	99.0	6
2,100	150	93	5	26	83	98.8	5
3,200	540	83	4	29	95	99.1	8
2,100	150	93	3	22	85	99.0	5
1,300	130	90	2	10	92	99.2	6
		90			89	99.0	

a - All quantities are expressed as arithmetic average.

TABLE V

COMPARISON OF COLIFORM REMOVAL BY SAND

AND DUAL-MEDIA FILTERS

Filter influent, coliforms/ 100 ml	Filtration rate gpm/ft^2	Filter effluent, coliforms/100 ml		% removal		No. of samples
		Sand	Dual-media	Sand	Dual-media	
		Winter series				
320	4	51	34	84	89	5
29	5	2	6	93	79	3
610	6	14	16	98	97	2
		Spring series				
540	4	28	12	95	98	4
150	5	26	38	83	75	5
130	6	13	12	90	91	6

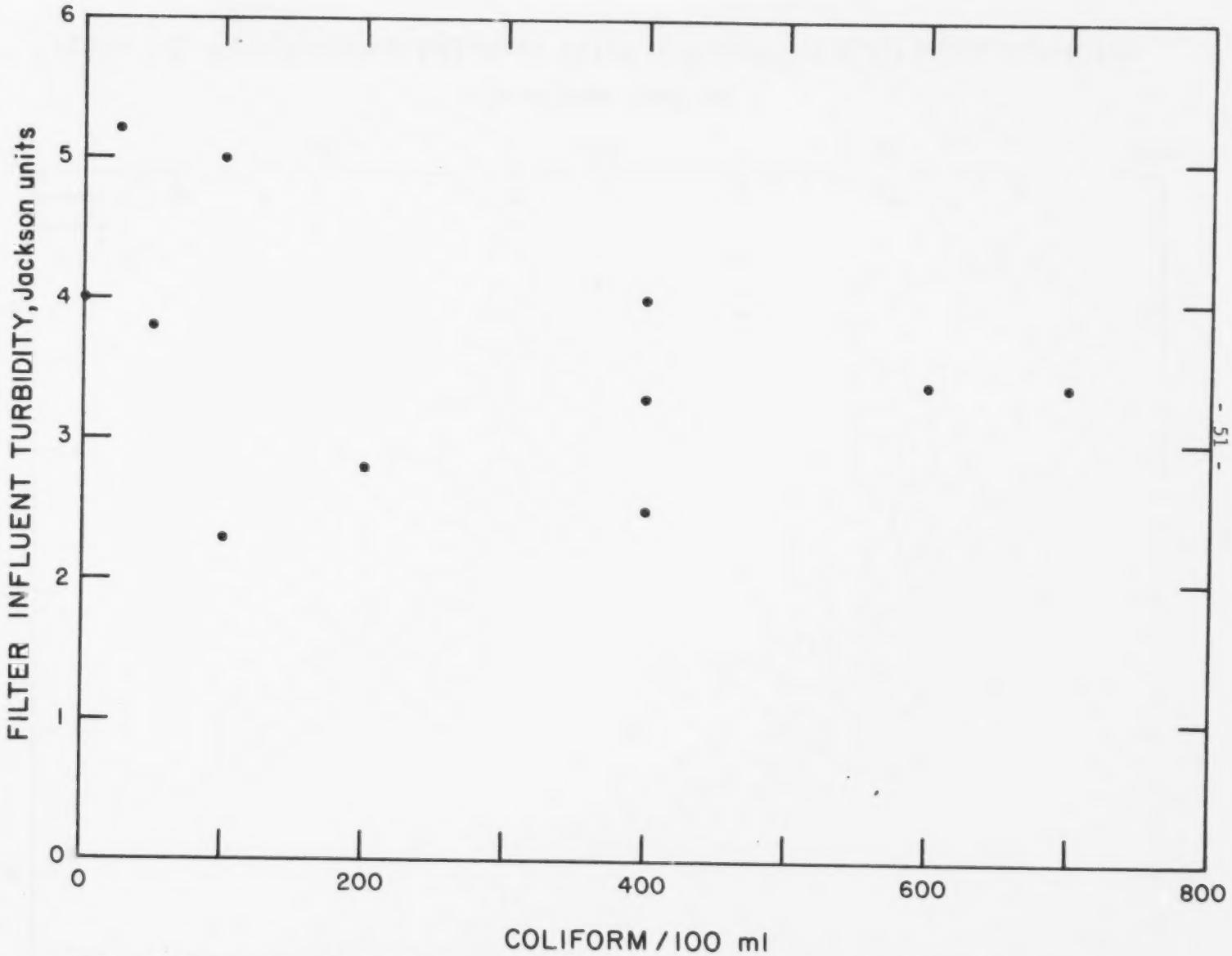

Figure 32. Relationship between filter influent turbidity and coliform count.

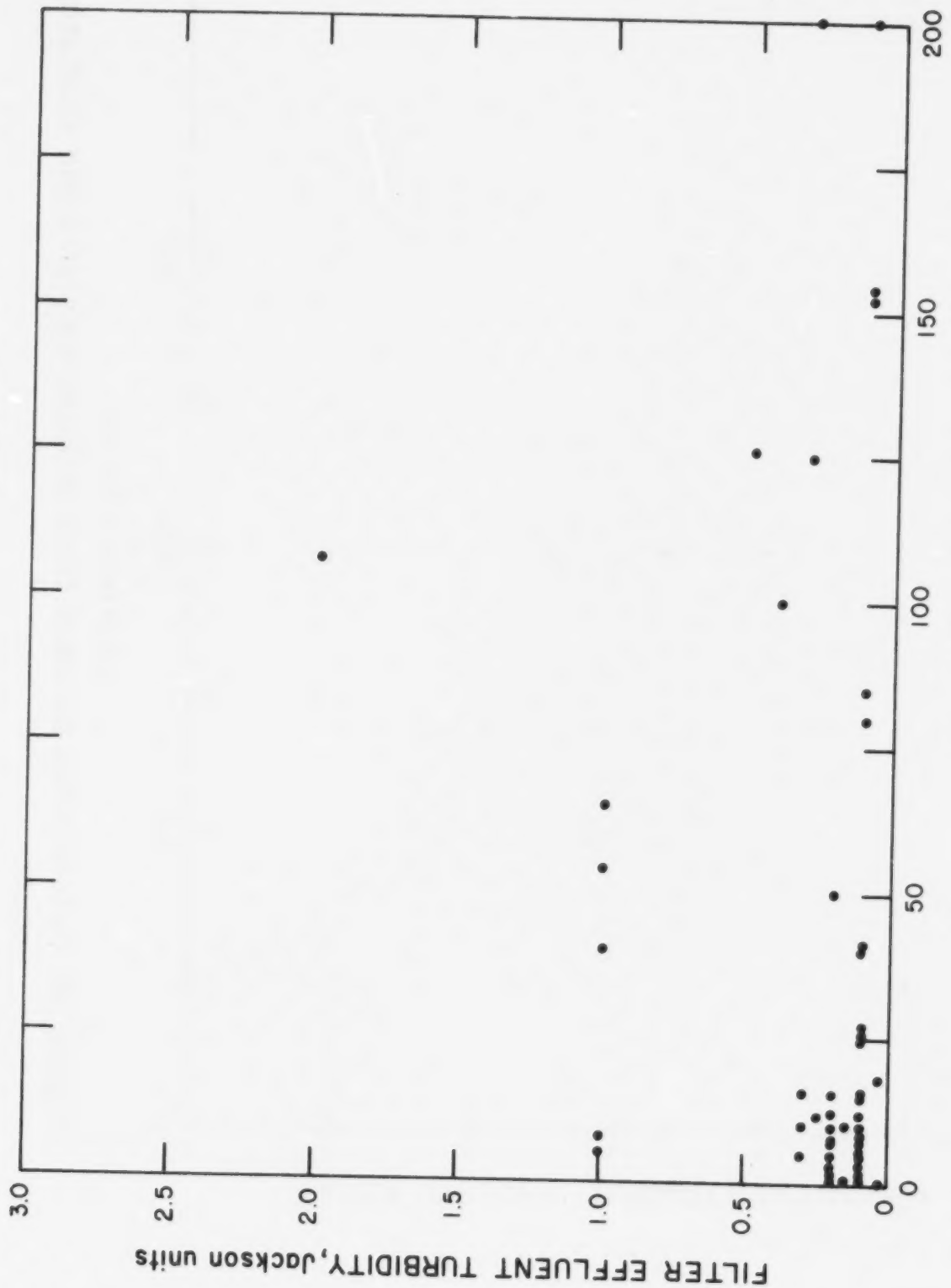

Figure 33. Relationship between filter effluent turbidity and coliform count.

Production Data

Production for all the filter runs, as measured by gallons of water filtered per square foot of filter surface per foot of developed headloss is shown in Table VI. Seasonal production averages for the sand and the dual-media filters are summarized in Table VII. The production for the sand filters shows a declining tendency from spring to winter as evidenced by the values of 2,900, 2,300, 1,600, and 1,400 gallons per square foot per foot of headloss increase, respectively, at the 3 gpm per square foot rate. Production for the dual-media filter averaged 2 to 2-1/2 times that of the sand filter operated at the corresponding rate as shown by the winter and spring averages. The highest average production of the dual-media filter was at the 5 gpm per square foot rate whereas the highest average production of the sand filter for the four seasons was at the 6 gpm per square foot rate.

TABLE VI

WATER PRODUCTION PER FOOT OF HEAD-LOSS INCREASE

Run no.	Date	Filtration rate, gpm/ft^2	Head loss, ft			Length of run hr	Production, 10^3 $gal/ft^2/\Delta h$
			Initial	Final	Δh		
			Summer series				
1	6/17/63	6	2.4	8.0	5.6	31	2.0
		2	1.3	5.6	4.3	36	1.0
2	6/19/63	6	2.6	7.1	4.5	28	2.2
		2	0.7	3.7	3.0	34	1.4
3	6/25/63	5	2.2	7.1	4.9	28	1.7
		3	1.0	6.8	5.8	38	1.2
4	6/26/63	5	2.4	7.3	4.9	14	0.9
		3	1.1	1.3	0.2	5	4.5
5	7/1/63	4	1.6	6.2	4.6	45	2.4
		4	1.6	6.0	4.4	45	2.5
6	7/8/63	6	2.6	6.2	3.6	35	3.5
		2	1.5	4.5	3.0	35	1.4
7	7/15/63	5	1.6	6.0	4.4	28	1.9
		3	1.8	6.0	4.2	28	1.2
8	7/22/63	4	1.6	4.6	3.0	30	2.4
		4	2.4	6.0	3.6	30	2.0
9	7/28/63	6	-	7.0	-	18	-
		2	-	2.0	-	18	-
			Fall Series				
1	9/24/63	6	3.4	6.4	3.0	22	2.6
		2	2.4	3.9	1.5	22	1.8
2	9/25/63	5	2.8	6.0	3.2	21	2.0
		3	2.7	4.9	2.2	21	1.7
3	10/2/63	4	2.2	6.0	3.8	30	1.9
		4	2.1	5.9	3.8	30	1.9
4	10/8/63	6	3.6	6.2	2.6	16	2.2
		2	1.0	2.0	1.0	16	1.9
5	10/9/63	5	2.6	6.2	3.6	22	1.8
		3	1.4	3.4	2.0	22	2.0

TABLE VI (Contd.)

Run no.	Date	Filtration rate, gpm/ft^2	Head loss, ft			Length of run hr	Production, 10^3 gal/ft^2/Δh
			Initial	Final	Δh		
6	10/14/63	4	2.4	6.8	4.4	26	1.4
		4	2.0	6.3	4.3	26	1.4
7	10/16/63	6	2.9	5.6	2.7	16	2.1
		2	1.2	2.8	1.6	16	1.2
8	10/22/63	5	2.7	6.0	3.3	16	1.4
		3	1.8	4.4	2.6	16	1.1
9	10/23/63	4	2.3	6.3	4.0	16	1.0
		4	2.0	6.0	4.0	16	1.0
			Winter series				
1	11/12/63	6	3.2	5.9	2.7	9.5	1.3
		6 (D)	1.4	6.2	4.8	30.0	2.3
		2	1.4	4.5	3.1	9.5	0.4
2	11/19/63	5	3.1	5.5	2.4	17.0	2.1
		5 (D)	1.1	6.1	5.0	84.0	5.0
		3	1.1	2.8	1.7	17.0	1.8
3	11/26/63	4	1.9	5.8	3.9	30.0	1.8
		4 (D)	0.9	6.0	5.1	83.0	3.9
		4	1.4	6.0	4.6	30.0	1.6
4	12/3/63	6	3.6	6.1	2.5	8.5	1.2
		6 (D)	1.4	6.0	4.6	44.0	3.4
		2	0.6	1.4	0.8	8.5	1.3
5	12/10/63	5	2.8	5.8	3.0	16.0	1.6
		5 (D)	1.1	6.0	4.9	55.0	3.4
		3	1.1	3.7	2.6	16.0	1.1
6	12/17/63	4	2.2	5.9	3.7	17.0	1.1
		4 (D)	0.9	6.2	5.3	47.0	2.1
		4	2.1	6.0	3.9	17.0	1.0
7	1/6/64	6	3.2	5.8	2.6	14.0	1.9
		6 (D)	1.5	5.9	4.4	30.0	2.5
		2	1.6	3.5	1.9	14.0	0.9
8	1/14/64	5	2.7	6.4	3.7	20.0	1.6
		5 (D)	1.1	6.0	4.9	48.0	2.9
		3	1.8	4.6	2.8	20.0	1.3

TABLE VI (Contd.)

Run no.	Date	Filtration rate gpm/ft^2	Head loss, ft.			Length of run hr	Production 10^3 gal/ft^2/Δh
			Initial	Final	Δh		
9	1/21/64	4	2.0	5.6	3.6	18	1.2
		4 (D)	0.9	6.2	5.3	49	2.2
		4	1.7	6.0	4.3	18	1.0
10	2/11/64	3	1.4	6.4	5.0	36	1.3
		3 (D)	0.7	6.3	5.6	111	3.6
		3	0.7	5.4	4.7	36	1.4
			Spring series				
1	3/3/64	6	3.0	5.8	2.8	14	1.8
		6 (D)	1.6	6.1	4.5	50	4.0
		2	0.4	1.6	1.2	14	1.4
2	2/11/64	5	2.3	5.9	3.6	14	1.2
		5 (D)	1.1	4.8	3.7	40	3.2
		3	2.2	2.8	0.6	14	4.2
3	3/15/64	4	1.6	5.7	4.1	26	1.5
		4 (D)	0.9	6.0	5.1	78	3.7
		4	1.4	5.8	4.4	26	1.4
4	3/24/64	6	3.2	5.9	2.7	18	2.4
		6 (D)	1.2	3.6	2.4	42	6.3
		2	0.4	1.5	1.1	18	2.0
5	4/7/64	5	1.0	4.9	3.9	38	2.9
		5 (D)	1.2	6.0	4.8	126	7.9
		3	0.1	3.0	2.9	38	2.4
6	4/14/64	4	1.4	6.0	4.6	36	1.9
		4 (D)	1.0	6.0	5.0	139	6.7
		4	1.8	5.5	3.7	36	2.3
7	4/29/64	6	2.9	6.0	3.1	23	2.7
		6 (D)	1.1	5.0	3.9	46	4.2
		2	0.8	2.6	1.8	23	1.5
8	5/5/64	5	1.9	5.7	3.8	38	3.0
		5 (D)	0.9	1.6	0.7	24	10.3
		3	1.2	4.5	3.3	38	2.1

TABLE VII

SUMMARY AND COMPARISON OF PRODUCTION

FOR SAND AND DUAL-MEDIA FILTERS

Filtration rate, gpm/ft^2	Production, 10^3 gal/ft^2/Δ ft					
	Summer	Fall	Winter	Spring	Winter and Spring	Annual
			Sand filters			
2	1.3	1.6	0.9	1.6	1.2	1.4
3	2.3	1.6	1.4	2.9	2.1	2.0
4	2.3	1.5	1.3	1.8	1.6	1.7
5	1.5	1.7	1.8	2.4	2.1	1.9
6	2.6	2.3	1.5	2.3	1.9	2.2
			Dual-Media Filters			
3	Not		3.6	-	-	-
4			2.7	5.2	4.0	-
5	Operating		3.8	7.1	5.4	-
6			2.7	4.8	3.8	-

DISCUSSION

Turbidity and coliform measurements of the raw water, filter influent, and filter effluent in the Easley plant showed that the filtration rates could be varied from 2 to 6 gpm per square foot without any significant degradation in the quality of the filtered water. When coagulation was not adequate, the turbidity breakthroughs occurring in the filters were occasionally more pronounced, although not more frequent, at the higher filtration rates. This study emphasized the fact that adequate chemical treatment before filtration is the primary requirement for continuous production of a high-quality water, regardless of filtration rate or type of filter media used. A simple jar test procedure coupled with continuous measurement of raw water turbidity would greatly enhance the effectiveness of the chemical treatment.

No correlation could be established between the turbidity of the filter influent or effluent and the coliform counts from these sources because insufficient grab samples were taken for coliform analysis. The great majority of coliform samples were not labeled as to sampling time and were, therefore, unusable for this type of correlation. It has been shown previously,[5] however, that increased turbidity in the filter effluent usually indicates an increased passage of organisms, if organisms were in the influent to the filter. Therefore, every effort should be made to fully utilize the settling basins and filters to produce the highest quality water possible. Such use could possibly decrease the chlorine demand of the finished water.

Measured by coliform and turbidity, the effluent from the dual-media filter was equal in quality to that of the sand filters operated at the same filtration rate. The dual-media filter run also lasted 2-1/2 times as long as that of the sand filters. These results support previous results obtained at the Sanitary Engineering Center.[2,5]

CONCLUSIONS

1. Increasing the filtration rate from 2 to 6 gpm per square foot through the sand-filter beds at the Easley, South Carolina, water plant did not affect the passage of turbidity or coliforms into the effluent significantly during the 1-year test period of 1963-64.

2. Increases in filter effluent turbidity did occasionally occur. During these periods, the effluent from the filter with the higher filtration rate sometimes reached a higher turbidity than the filter with the lower filtration rate, but both recovered with equal rapidity when remedial steps were taken to insure adequate coagulation.

3. Sudden increases in raw water turbidity appeared to cause many of the coagulation difficulties.

4. Seasonal factors were not significant to the overall plant removal of coliforms.

5. Overloading of the settling tanks did not affect effluent quality when adequate coagulation was provided.

6. When operated at the same rate, the dual-media filter permitted filtration runs 2-1/2 times longer than the sand filters and produced an effluent of equal quality.

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